EPA

United States
Environmental Protection
Agency

Regional Benefits Analysis for the Final Section 316(b) Phase III Existing Facilities Rule

June 2006

U.S. Environmental Protection Agency
Office of Water (4303T)
1200 Pennsylvania Avenue, NW
Washington, DC 20460

EPA-821-R-04-007

Table of Contents

Introduction

Part A: Evaluation Methods

Chapter A1: Methods Used to Evaluate I&E

A1-1 Objectives of EPA's Evaluation of I&E Data
A1-2 Rationale for EPA's Approach to Evaluating I&E of Harvested Species
A1-3 Source Data
A1-4 Methods for Evaluating I&E
A1-5 Extrapolation of I&E Rates

Chapter A2: Uncertainty

A2-1 Types of Uncertainty
A2-2 Monte Carlo Analysis as a Tool for Quantifying Uncertainty
A2-3 EPA's Uncertainty Analysis of Yield Estimates
A2-4 Conclusions

Chapter A3: Economic Benefit Categories and Valuation

A3-1 Economic Benefit Categories Applicable to the Regulatory Analysis Options for Phase III Facilities
A3-2 Direct Use Benefits
A3-3 Indirect Use Benefits
A3-4 Non-Use Benefits
A3-5 Summary of Benefit Categories
A3-6 Causality: Linking the Regulatory Analysis Options for Phase III Existing Facilities to Beneficial Outcomes
A3-7 Conclusions

Chapter A4: Methods for Estimating Commercial Fishing Benefits

A4-1 Overview of the Commercial Fisheries Sector
A4-2 The Role of Fishing Regulations and Regulatory Participants
A4-3 Overview of U.S. Commercial Fisheries
A4-4 Prices, Quantities, Gross Revenue, and Economic Surplus
A4-5 Economic Surplus
A4-6 Surplus Estimation When There is No Anticipated Change in Price
A4-7 Surplus Estimation Under Scenarios in Which Price May Change
A4-8 Estimating Post-Harvest Economic Surplus in Tiered Markets
A4-9 Nonmonetary Benefits of Commercial Fishing
A4-10 Estimating Producer Surplus
A4-11 Methods Used to Estimate Commercial Fishery Benefits from Reduced I&E; Summary
A4-12 Limitations and Uncertainties

Chapter A5: Recreational Fishing Benefits Methodology

A5-1 Literature Review Procedure and Organization
A5-2 Description of Studies
A5-3 Meta-Analysis of Recreational Fishing Studies: Regression Model
A5-4 Application of the Meta-Analysis Results to the Analysis of Recreational Benefits of the Section 316(b) Regulatory Analysis Options for Phase III Facilities
A5-5 Limitations and Uncertainties

Chapter A6: Qualitative Assessment of Non-Use Benefits
A6-1 Public Policy Significance of Ecological Improvements from the Regulatory Analysis Options for Phase III Facilities

Chapter A7: Entrainment Survival
A7-1 The Causes of Entrainment Mortality
A7-2 Factors Affecting the Determination of Entrainment Survival
A7-3 Detailed Analysis of Entrainment Survival Studies Reviewed
A7-4 Discussion of Review Criteria
A7-5 Applicability of Entrainment Survival Studies to Other Facilities
A7-6 Conclusions

Chapter A8: Discounting Benefits
A8-1 Timing of Benefits
A8-2 Discounting and Annualization

Chapter A9: Threatened & Endangered Species Analysis Methods
A9-1 Listed Species Background
A9-2 Benefit Categories Applicable for Impacts on T&E Species
A9-3 Methods Available for Estimating the Economic Value Associated with I&E of T&E Species
A9-4 Issues in Estimating and Valuing Environmental Impacts from I&E on T&E Species

Part B: California

Chapter B1: Background
B1-1 Facility Characteristics

Chapter B2: Evaluation of Impingement and Entrainment in California
B2-1 I&E Species/Species Groups Evaluated
B2-2 I&E Data Evaluated
B2-3 EPA's Estimate of Current I&E at Phase III Facilities in California Expressed as Age-1 Equivalents and Foregone Yield
B2-4 Reductions in I&E at Phase III Facilities in the California Region Under Alternative Options
B2-5 Assumptions Used in Calculating Recreational and Commercial Losses

Chapter B3: Commercial Fishing Benefits
B3-1 Baseline Commercial Losses
B3-2 Expected Benefits Under Regulatory Analysis Options

Chapter B4: Recreational Use Benefits
B4-1 Benefit Transfer Approach Based on Meta-Analysis
B4-2 Limitations and Uncertainty

Chapter B5: Federally Listed T&E Species in the California Region

Appendix B1: Life History Parameter Values Used to Evaluate I&E in the California Region
Appendix B2: Reductions in I&E Under Supplemental Policy Options
Appendix B3: Commercial Fishing Benefits Under Supplemental Policy Options
Appendix B4: Recreational Use Benefits Under Supplemental Policy Options

Part C: North Atlantic

Chapter C1: Background
C1-1 Facility Characteristics

Chapter C2: Evaluation of Impingement and Entrainment in the North Atlantic Region
C2-1 I&E Species/Species Groups Evaluated
C2-2 I&E Data Evaluated
C2-3 EPA's Estimate of Current I&E at Phase III Facilities in the North Atlantic Region Expressed as Age-1 Equivalents and Foregone Yield
C2-4 Reductions in I&E at Phase III Facilities in the North Atlantic Region Under Alternative Options
C2-5 Assumptions Used in Calculating Recreational and Commercial Losses

Chapter C3: Commercial Fishing Benefits
C3-1 Baseline Commercial Losses
C3-2 Expected Benefits Under Regulatory Analysis Options

Chapter C4: Recreational Use Benefits
C4-1 Benefit Transfer Approach Based on Meta-Analysis
C4-2 Limitations and Uncertainty

Chapter C5: Federally Listed T&E Species in the North Atlantic Region

Appendix C1: Life History Parameter Values Used to Evaluate I&E in the North Atlantic Region
Appendix C2: Reductions in I&E Under Supplemental Policy Options
Appendix C3: Commercial Fishing Benefits Under Supplemental Policy Options
Appendix C4: Recreational Use Benefits Under Supplemental Policy Options

Part D: Mid-Atlantic Region

Chapter D1: Background
D1-1 Facility Characteristics

Chapter D2: Evaluation of Impingement and Entrainment in the Mid-Atlantic Region
D2-1 I&E Species/Species Groups Evaluated
D2-2 I&E Data Evaluated
D2-3 EPA's Estimate of Current I&E at Phase III Facilities in the Mid-Atlantic Region Expressed as Age-1 Equivalents and Foregone Yield
D2-4 Reductions in I&E at Phase III Facilities in the Mid-Atlantic Region Under Alternative Options
D2-5 Assumptions Used in Calculating Recreational and Commercial Losses

Chapter D3: Commercial Fishing Benefits
D3-1 Baseline Commercial Losses
D3-2 Expected Benefits Under Regulatory Analysis Options

Chapter D4: Recreational Use Benefits
D4-1 Benefit Transfer Approach Based on Meta-Analysis
D4-2 Limitations and Uncertainty

Chapter D5: Federally Listed T&E Species in the Mid-Atlantic Region

Appendix D1: Life History Parameter Values Used to Evaluate I&E in the Mid-Atlantic Region
Appendix D2: Reductions in I&E Under Supplemental Policy Options
Appendix D3: Commercial Fishing Benefits Under Supplemental Policy Options
Appendix D4: Recreational Use Benefits Under Supplemental Policy Options

Part E: Gulf of Mexico

Chapter E1: Background
E1-1 Facility Characteristics

Chapter E2: Evaluation of Impingement and Entrainment in the Gulf of Mexico
E2-1 I&E Species/Species Groups Evaluated
E2-2 I&E Data Evaluated
E2-3 EPA's Estimate of Current I&E at Phase III Facilities in the Gulf Region Expressed as Age-1 Equivalents and Foregone Yield
E2-4 Reductions in I&E at Phase III Facilities in the Gulf of Mexico Region Under Alternative Options
E2-5 Assumptions Used in Calculating Recreational and Commercial Losses

Chapter E3: Commercial Fishing Benefits
E3-1 Baseline Commercial Losses
E3-2 Expected Benefits Under Regulatory Analysis Options

Chapter E4: Recreational Use Benefits
E4-1 Benefit Transfer Approach Based on Meta-Analysis
E4-2 Limitations and Uncertainty

Chapter E5: Federally Listed T&E Species in the Gulf of Mexico Region

Appendix E1: Life History Parameter Values Used to Evaluate I&E in the Gulf of Mexico Region
Appendix E2: Reductions in I&E Under Supplemental Policy Options
Appendix E3: Commercial Fishing Benefits Under Supplemental Policy Options
Appendix E4: Recreational Use Benefits Under Supplemental Policy Options

Part F: The Great Lakes

Chapter F1: Background
F1-1 Facility Characteristics

Chapter F2: Evaluation of Impingement and Entrainment in the Great Lakes Region
F2-1 I&E Species/Species Groups Evaluated
F2-2 I&E Data Evaluated
F2-3 EPA's Estimate of Current I&E at Phase III Facilities in the Great Lakes Region Expressed as Age-1 Equivalents and Foregone Yield
F2-4 Reductions in I&E at Phase III Facilities in the Great Lakes Region Under Alternative Options
F2-5 Assumptions Used in Calculating Recreational and Commercial Losses

Chapter F3: Commercial Fishing Benefits
F3-1 Baseline Commercial Losses
F3-2 Expected Benefits Under Regulatory Analysis Options

Chapter F4: Recreational Use Benefits
F4-1 Benefit Transfer Approach Based on Meta-Analysis
F4-2 Limitations and Uncertainty

Chapter F5: Federally Listed T&E Species in the Great Lakes Region

Appendix F1: Life History Parameter Values Used to Evaluate I&E in the Great Lakes Region
Appendix F2: Reductions in I&E Under Supplemental Policy Options
Appendix F3: Commercial Fishing Benefits Under Supplemental Policy Options
Appendix F4: Recreational Use Benefits Under Supplemental Policy Options

Part G: The Inland Region

Chapter G1: Background
G1-1 Facility Characteristics

Chapter G2: Evaluation of Impingement and Entrainment in the Inland Region
G2-1 I&E Species/Species Groups Evaluated
G2-2 I&E Data Evaluated
G2-3 EPA's Estimate of Current I&E at Phase III Facilities in the Inland Region Expressed as Age-1 Equivalents and Foregone Yield
G2-4 Reductions in I&E at Phase III Facilities in the Inland Region Under Alternative Options
G2-5 Assumptions Used in Calculating Recreational and Commercial Losses

Chapter G3: Commercial Fishing Benefits

Chapter G4: Recreational Use Benefits
G4-1 Benefit Transfer Approach Based on Meta-Analysis
G4-2 Limitations and Uncertainty

Chapter G5: Federally Listed T&E Species in the Inland Region

Appendix G1: Life History Parameter Values Used to Evaluate I&E in the Inland Region
Appendix G2: Reductions in I&E Under Supplemental Policy Options
Appendix G3: Commercial Fishing Benefits Under Supplemental Policy Options
Appendix G4: Recreational Use Benefits Under Supplemental Policy Options

Part H: South Atlantic

Chapter H1: Background
H1-1 Facility Characteristics

Chapter H2: Evaluation of Impingement and Entrainment in the South Atlantic Region
H2-1 I&E Species/Species Groups Evaluated
H2-2 I&E Data Evaluated
H2-3 EPA's Estimate of Current I&E at Phase III Facilities in the South Atlantic Region Expressed as Age-1 Equivalents and Foregone Yield
H2-4 Reductions in I&E at Phase III Facilities in the South Atlantic Region
H2-5 Assumptions Used in Calculating Recreational and Commercial Losses

Chapter H3: Commercial Fishing Benefits
H3-1 Baseline Commercial Losses
H3-2 Expected Benefits Under Regulatory Analysis Options

Chapter H4: Recreational Use Benefits
H4-1 Benefit Transfer Approach Based on Meta-Analysis
H4-2 Limitations and Uncertainty

Chapter H5: Federally Listed T&E Species in the South Atlantic Region

Appendix H1: Life History Parameter Values Used to Evaluate I&E in the South Atlantic Region
Appendix H2: Reductions in I&E Under Supplemental Policy Options
Appendix H3: Commercial Fishing Benefits Under Supplemental Policy Options
Appendix H4: Recreational Use Benefits Under Supplemental Policy Options

Part I: National Benefits

Chapter I1: National Benefits
I1-1 Calculating National Losses and Benefits
I1-2 Summary of Baseline Losses and Expected Reductions in I&E
I1-3 Time Profile of Benefits
I1-4 National Benefits from Eliminating and Reducing I&E Losses

Appendix I1: National Benefits Under Supplemental Policy Options

References

Introduction

Introduction

Contents

1-1 Summary of the Regulatory and Supplemental Options 1-1
1-2 Study Design 1-4
  1-2.1 Coastal Regions 1-5
  1-2.2 Great Lakes Region 1-5
  1-2.3 Inland Region 1-5
1-3 Report Organization 1-5
  1-3.1 Part A: Study Methods 1-5
  1-3.2 Parts B-H: Regional Reports 1-6
  1-3.3 Part I: Total National Benefits 1-6

Cooling water intake structures (CWIS) may cause adverse environmental impact (AEI) through several means, including impingement (where fish and other aquatic life are trapped on equipment at the entrance to CWIS) and entrainment (where eggs, larvae, and other aquatic organisms are taken into the cooling system, passed through the heat exchanger, and then discharged back into the source water body).

Facilities potentially subject to regulation under Phase III of the 316(b) rulemaking process include the following types of facilities that employ a cooling water intake structure and are designed to withdraw two million gallons per day (MGD) or more from waters of the United States: (1) existing manufacturing and other types of existing facilities, e.g., offshore oil and gas extraction facilities (this group of facilities is referred to as “manufacturing facilities” in this document); (2) existing electric power producing facilities with a design intake flow (DIF) of less than 50 million MGD; and (3) new offshore oil and gas extraction facilities. These facilities are referred to as a group as “potential Phase III facilities.” Phase III does not include facilities regulated under Phase I (new facilities other than new offshore oil and gas extraction facilities) or Phase II (existing power producing facilities with a DIF of 50 MGD or greater). More information on the regulated sectors and facilities can be found in the *Economic and Benefits Analysis for the Final Section 316(b) Phase III Existing Facilities Rule* (U.S. EPA, 2006a).

This Regional Benefits Assessment presents the methods used by EPA for the environmental assessment and benefits analysis for the regulatory analysis options considered. EPA’s analysis had three main objectives: (1) to develop a national estimate of the magnitude of impingement and entrainment (I&E) at potentially regulated Phase III facilities; (2) to estimate changes in the I&E losses as a result of projected reductions in I&E under the various analysis options; and (3) to estimate the national economic benefits of reduced I&E. The environmental assessment and benefits analyses presented in this report examines electric generators and most manufacturing facilities subject to the 316(b) Phase III regulation. EPA was unable to assess benefits in the same manner for existing offshore oil and gas extraction facilities due to I&E data limitations. In addition, EPA did not quantitatively assess benefits for new offshore oil and gas extraction facilities because to do so would require EPA to project where the new facilities would locate and operate in the future, a task for which EPA does not have sufficient information at this time. Part A of the document provides details of the methods used. Parts B-H present reports of results for each of seven study regions. Finally, Part I presents national estimates. The following sections provide an overview of the study design and a summary of the contents of each part of the document.

1-1 Summary of the Regulatory and Supplemental Options

EPA considered requirements for Phase III existing facilities to meet performance standards similar to those required in the final Phase II rule, including an 80-95% reduction in impingement mortality and a 60-90% reduction in entrainment. In the final Phase III rule, however, EPA determined that uniform national standards are not the most effective way to address cooling water intake structures at existing Phase III facilities. Phase III existing facilities continue to be subject to permit conditions implementing section 316(b) of the Clean Water Act set by the permit director on a case-by-case basis, using best professional judgment (BPJ).

The performance standards presented at proposal were intended to reflect the best technology available for minimizing AEIs determined on a national categorical basis. The type of performance standard applicable to a particular facility (i.e., reductions in impingement only or I&E) would have varied based on several factors, including the facility's location (i.e., source waterbody) and the proportion of the waterbody withdrawn. Impingement reductions were required at all facilities subject to the performance standards. Entrainment reductions are required at facilities (1) located on an estuary, tidal river, ocean, or one of the Great Lakes; or (2) located on a freshwater river and withdrawing greater than 5% of the mean annual flow of the waterbody. At proposal, facilities located on lakes or reservoirs may not disrupt the thermal stratification of the waterbody, except in cases where the disruption is beneficial to the management of fisheries.

EPA proposed three possible options for defining which existing manufacturing facilities would be subject to uniform national requirements, based on DIF threshold and source waterbody type: the facility has a total DIF of 50 MGD or more, and withdraws from any waterbody; the facility has a total DIF of 200 MGD or more, and withdraws from any waterbody; or the facility has a total DIF of 100 MGD or more and withdraws water specifically from an ocean, estuary, tidal river, or one of the Great Lakes. These are options 5, 9, and 8, respectively, in Table 1-1 below.

In addition, EPA considered a number of options (specifically options 2, 3, 4, and 7 below) that establish different performance standards for certain groups or subcategories of Phase III existing facilities. Under these options, EPA would have applied the proposed performance standards and compliance alternatives (i.e., the Phase II requirements) to the higher threshold facilities, apply the less-stringent requirements as specified below to the middle flow threshold category, and would apply BPJ below the lower threshold.

The regulatory options as well as other options considered are described in detail below:

Option 1: Facilities with a DIF of 20 MGD or greater would be subject to the performance standards discussed above. Under this option, section 316(b) permit conditions for Phase III facilities with a DIF of less than 20 MGD would be established on a case-by-case, BPJ, basis.

Option 2: Facilities with a DIF of 50 MGD or greater, as well as facilities with a DIF between 20 and 50 MGD (20 MGD inclusive), when located on estuaries, oceans, or the Great Lakes would be subject to the performance standards. Facilities with a DIF between 20 and 50 MGD (20 MGD inclusive) that withdraw from freshwater rivers and lakes would have to meet the performance standards for impingement mortality only and not for entrainment. Under this option, section 316(b) requirements for Phase III facilities with a DIF of less than 20 MGD would be established on a case-by-case, BPJ, basis.

Option 3: Facilities with a DIF of 50 MGD or greater would be subject to the performance standards. Facilities with a DIF between 20 and 50 MGD (20 MGD inclusive) would have to meet the performance standards for impingement mortality only and not for entrainment. Under this option, section 316(b) requirements for Phase III facilities with a DIF of less than 20 MGD would be established on a case-by-case, BPJ, basis.

Option 4: Facilities with a DIF of 50 MGD or greater, as well as facilities with a DIF between 20 and 50 MGD (20 MGD inclusive), when located on estuaries, oceans, or the Great Lakes would be subject to the performance standards. Facilities that withdraw from freshwater rivers and lakes and all facilities with a DIF of less than 20 MGD would have requirements established on a case-by-case, BPJ, basis.

Option 5: Facilities with a DIF of 50 MGD or greater would be subject to the performance standards. Under this option, section 316(b) requirements for Phase III facilities with a DIF of less than 50 MGD would be established on a case-by-case, BPJ, basis.

Option 6: Facilities with a DIF of greater than 2 MGD would be subject to the performance standards. Under this option, section 316(b) requirements for Phase III facilities with a DIF of 2 MGD or less would be established on a case-by-case, BPJ, basis.

Option 7: Facilities with a DIF of 50 MGD or greater would be subject to the performance standards. Facilities with a DIF between 30 and 50 MGD (30 MGD inclusive) would have to meet the performance standards for impingement mortality only and not for entrainment. Under this option, section 316(b) requirements for Phase III facilities with a DIF of less than 30 MGD would be established on a case-by-case, BPJ, basis.

Option 8: Facilities with a DIF of 200 MGD or greater would be subject to the performance standards. Under this option, section 316(b) requirements for Phase III facilities with a DIF of less than 200 MGD would be established on a case-by-case, BPJ, basis.

Option 9: Facilities with a DIF of 100 MGD or greater and located on oceans, estuaries, and the Great Lakes would be subject to the performance standards. Under this regulatory option, section 316(b) requirements for Phase III facilities with a DIF of less than 100 MGD would be established on a case-by-case, BPJ, basis.

Table 1-1 summarizes which performance standards apply under each of the proposed options considered for Phase III existing facilities (options 5, 8, and 9) as well as the other options considered:

Table 1-1: Performance Standards for the Regulatory Options Considered

Option	Minimum DIF Defining Facilities as Existing Phase III Facilities					
	> 2 MGD	20 MGD	30 MGD	50 MGD	100 MGD	200 MGD
1	BPJ	I&E				
2	BPJ	Freshwater rivers and lakes: I only All other waterbodies: I&E		I&E		
3	BPJ	I only		I&E		
4	BPJ	Estuaries, oceans, Great Lakes: I&E All other waterbodies: BPJ		I&E		
5	BPJ			I&E		
6	I&E					
7	BPJ		I only	I&E		
8	BPJ					I&E
9	BPJ				Estuaries, oceans, Great Lakes: I&E All other waterbodies: BPJ	

Key:

BPJ – Best Professional Judgment.
I&E – 80-95% reduction in impingement mortality and a 60-90% reduction in entrainment, where applicable.
I only – 80-95% reduction in impingement mortality.
Estuaries – includes tidal rivers and streams.
Lakes – includes lakes and reservoirs.

The discussions in the remainder of this document focus on the three regulatory options comprising the regulatory proposal (i.e., Options 5, 8, and 9). In the remainder of this document, these three options are referred to as follows:

Option 5, which would have applied to existing manufacturing facilities with a total DIF of **50 MGD or more** and located on **any source waterbody type** is referred to as the **“50 MGD for All Waterbodies” option** or the **“50 MGD All” option**.

Option 8, which would have applied to existing manufacturing facilities with a total DIF of **200 MGD or more** and located on **any source waterbody type** is referred to as the **"200 MGD for All Waterbodies" option** or the **"200 MGD All" option**.

Option 9, which would have applied to existing manufacturing facilities with a total DIF of **100 MGD or more** and located on **certain source waterbody types** (i.e., an ocean estuary, tidal river/stream, or one of the Great Lakes) is referred to as the **"100 MGD for Certain Waterbodies" option** or the **"100 MGD CWB" option**.

In addition to these three regulatory analysis options, this document also presents information on the other options that EPA analyzed in development of the Phase III proposal and the final regulation (i.e., Options 2, 3, 4, and 7, also referred to as the "supplemental options"). The information for the supplemental options is presented in appendices to the relevant chapters in this report.

1-2 Study Design

EPA's analysis of the regulation examined cooling water intake structure impacts and regulatory benefits at the regional scale, and then combined regional results to develop national estimates. EPA grouped facilities into regions for its analysis based on (1) the locations of facilities potentially subject to regulation in Phase III, (2) similarities among the aquatic species affected by these facilities, and (3) characteristics of commercial and recreational fishing activities in the area. Table 1-2 lists the number of potentially regulated facilities in each study region and the number of facilities with technology requirements under each of the regulatory analysis options, weighted using statistical weights from EPA's survey of the industry. The seven regions and the waterbody types within each region are described below. Maps showing the facilities in each region are provided in the introductory chapter of each regional report (Parts B-H of this document).

Table 1-2: Number of Existing Phase III Facilities by Region and Option

Region	# of Potentially Regulated Existing Phase III Facilities (weighted)[a]	# of Facilities Subject to National Technology Requirements (weighted)		
		50 MGD All	200 MGD All	100 MGD CWB
California[b]	9	1	0	0
North Atlantic	5	4	1	3
Mid-Atlantic	15	3	2	2
South Atlantic	4	0	0	0
Gulf of Mexico	11	7	3	7
Great Lakes	45	18	7	10
Inland	540	78	13	0
National total[b,c]	629	111	27	22

[a] Potentially regulated existing Phase III facilities include electric generators with CWIS that withdraw more than 2 MGD but less than 50 MGD and manufacturers with CWIS that withdraw more than 2 MGD and use at least 25% of the water for cooling purposes.
[b] Numbers may not sum to totals due to independent rounding.
[c] Eighty potentially regulated facilities determined to be baseline closures are excluded from this analysis.

1-2.1 Coastal Regions

Coastal regions include estuary/tidal river and ocean facilities in five of the NOAA Fisheries regions. The North Atlantic region encompasses Maine, New Hampshire, Massachusetts, Connecticut, and Rhode Island. The Mid-Atlantic region includes New York, New Jersey, Maryland, the District of Columbia, Delaware, and Virginia. The Gulf of Mexico region includes Texas, Louisiana, Mississippi, Alabama, and the west coast of Florida. The California region includes all estuary/tidal river and ocean facilities in California, plus one facility in Hawaii. Although the Hawaii facility was considered in estimating baseline I&E in the California region, it is not subject to any of the options described in Table 1-2. Therefore no benefits are anticipated for this facility. The South Atlantic region includes North Carolina, South Carolina, Georgia, and the east coast of Florida. In the South Atlantic, all known in-scope facilities have DIFs that are less then 50 MGD, and therefore none are subject to the options described in Table 1-2. EPA's survey did not locate any Phase III facilities within the Alaska NOAA Fisheries region. Although one Phase III facility is located in the Pacific Northwest Fisheries region, this facility is projected to close under the baseline scenario. Therefore, EPA did not include analysis of these two regions in this assessment.

1-2.2 Great Lakes Region

The Great Lakes region includes all potentially regulated Phase III facilities that withdraw water from Lake Ontario, Lake Erie, Lake Huron (including Lake St. Clair), Lake Michigan, and Lake Superior, and the connecting channels (Saint Mary's River, Saint Clair River, Detroit River, Niagara River, and Saint Lawrence River to the Canadian border). This region definition is based on the definition provided in Section 118(a)(3)(B) of the Clean Water Act.

1-2.3 Inland Region

The Inland region includes all facilities located on freshwater rivers or streams and lakes or reservoirs, in all states, with the exception of facilities located in the Great Lakes region.

1-3 Report Organization

1-3.1 Part A: Study Methods

1-3.1.1 Evaluation of I&E

Chapter A1 of Part A of this Regional Benefits Assessment describes the methods used to evaluate facility I&E data. Chapter A2 discusses uncertainties in the analysis. To obtain regional I&E estimates, EPA extrapolated loss rates from those facilities for which I&E data is available, referred to in this document as model facilities, to all Phase III facilities within the same region. These results were then summed to develop national estimates. EPA used I&E data from Phase II facilities to supplement the limited data available for Phase III facilities.

1-3.1.2 Economic Benefits

Chapters A3-A6 and A8-A9 of Part A of this document describe the methods that EPA used for its analysis of the economic benefits of the section 316(b) rule for Phase III facilities. As discussed in Chapter A3, EPA considered the following benefit categories: recreational fishing benefits, commercial fishing benefits, and non-use benefits. The analysis of use benefits included benefits from improved commercial fishery yields and benefits to recreational anglers from improved fishing opportunities. Chapters A4 and A5 provide details on the methods used for these analyses. Chapter A6 presents qualitative assessment of ecological non-use benefits of the regulation. Non-use benefits included benefits from reduced I&E of forage species, and the non-landed portion of commercial and recreational species. Chapter A8 discusses discounting of recreational and commercial benefits. Methods for estimating benefits to threatened and endangered species are described in Chapter A9.

1-3.2 Parts B-H: Regional Reports

Parts B-H of this Regional Benefits Assessment are reports of results for each study region. Chapter 1 of each report provides background information on the facilities in the region and a map showing facility locations. Chapter 2 provides I&E estimates. Benefits estimates are presented in Chapters 3 and 4. Chapter 3 presents estimates of commercial fishing benefits, and Chapter 4 presents recreational fishing benefits. Chapter 5 presents information on threatened and endangered species in each region. Appendix 1 of each regional report presents life history data and the data sources used in evaluations of I&E, and Appendix 2 presents results for supplementary policy options. Please see the TDD for additional information.

1-3.3 Part I: Total National Benefits

Chapter I1 summarizes the results of the seven regional analyses and presents the total monetary value of national baseline losses and benefits for all section 316(b) Phase III manufacturing facilities (except oil and gas extraction facilities) and power generators.

Part A: Evaluation Methods

Chapter A1: Methods Used to Evaluate I&E

Introduction

This chapter describes the methods used by EPA to evaluate facility impingement and entrainment (I&E) data. Section A1-1 discusses the main objectives of EPA's I&E evaluation. Section A1-2 describes EPA's general approach to modeling fishery yield and the rationale for this approach. Section A1-3 describes the source data for EPA's I&E evaluations. Section A1-4 presents details of the biological models used to evaluate I&E. Finally, section A1-5 discusses methods used to extrapolate I&E rates from facilities with I&E data to other facilities in the same region without data.

Chapter Contents

A1-1 Objectives of EPA's Evaluation of I&E Data A1-1
A1-2 Rationale for EPA's Approach to Evaluating I&E of Harvested Species A1-1
  A1-2.1 Scope and Objectives of EPA's Analysis of Harvested Species........ A1-2
  A1-2.2 Data Availability and Uncertainties.................................. A1-2
  A1-2.3 Difficulties Distinguishing Causes of Population Changes.................... A1-3
A1-3 Source Data A1-3
  A1-3.1 Facility Impingement and Entrainment Monitoring Data......... A1-3
  A1-3.2 Species Groups A1-4
  A1-3.3 Species Life History Parameters..... A1-4
A1-4 Methods for Evaluating I&E A1-5
  A1-4.1 Modeling Age-1 Equivalents.......... A1-5
  A1-4.2 Modeling Foregone Fishery Yield A1-6
  A1-4.3 Modeling Production Foregone A1-9
  A1-4.4 Evaluation of Forage Species Losses A1-10
A1-5 Extrapolation of I&E Rates........................ A1-11

A1-1 Objectives of EPA's Evaluation of I&E Data

EPA's evaluation of I&E data had four main objectives:

- to develop a national estimate of the magnitude of I&E;
- to standardize I&E rates using common biological metrics so that rates could be compared across species, years, facilities, and geographical regions;
- to estimate changes in these metrics as a result of projected reductions in I&E under the proposed regulatory options for the section 316(b) Phase III existing facilities rule; and
- to estimate the national economic benefits of reduced I&E.

To accomplish these objectives, three loss metrics were derived from the facility I&E monitoring data available to EPA: (1) foregone age-1 equivalents, (2) foregone fishery yield, and (3) foregone biomass production. The methods used to calculate these metrics are described in section A1-4. Age-1 equivalent estimates were used to quantify losses of individuals in terms of a single life stage. Losses of commercial and recreational species were also expressed as foregone fishery yield. Estimates of production foregone were used to quantify the contribution of forage species to the yield of harvested species. The following section discusses EPA's rationale for evaluating the I&E of harvested species in terms of foregone fishery yield. Foregone fishery yield is also referred to as harvest in the discussion below.

A1-2 Rationale for EPA's Approach to Evaluating I&E of Harvested Species

EPA estimated I&E impacts to all fish and shellfish species for which data were available. EPA focused on harvested fish and shellfish species primarily because of the availability of economic methods for valuing these species (see Chapters A3-A6 and A8-A9 for a discussion of all of the economic methods used by EPA to estimate benefits of the proposed regulatory options for the section 316(b) rule for Phase III existing facilities). EPA's approach to estimating changes in harvest assumed that I&E losses result in a reduction in the number of harvestable adults in the years following the time at which individual fish are killed by I&E and that future reductions in I&E will lead to future increases in fish harvest. The approach does not require knowledge of population size or the total yield of a fishery; it only estimates the incremental yield that is foregone because of the number of deaths due to I&E.

As discussed in detail in section A1-4.2, EPA's foregone fishery yield analysis employed a specific application of the Thompson Bell model of fisheries yield (Ricker, 1975) to assess the effects of I&E on net fish harvest. This model is a relatively simple yield-per-recruit (YPR) model that provides estimates of yield that can be expected from a cohort of fish that is recruited to a fishery. The model requires estimates of size-at-age for particular species and stage-specific schedules of natural mortality (M) and fishing mortality (F). All of the key parameters used in the yield model (F, M, and size-at-age), were assumed to be constant for a given species regardless of changes in I&E rates. Because these parameters are held static for any particular fish stock, YPR is also a constant value. With this set of parameters fixed, the Thompson Bell model holds that an estimate of recruitment is directly proportional to an estimate of yield.

EPA recognizes that the assumption that the key parameters are static is an important one that does not fully reflect the dynamic nature of fish populations. However, by focusing on a simple interpretation of each individual I&E death in terms of foregone yield, EPA concentrated on the simplest, most direct assessment of the potential economic value of eliminating that death. EPA believes that this approach was warranted given the (1) scope and objectives of its analysis of harvested species, (2) data available, and (3) difficulties in distinguishing the causes of population changes. Each of these factors is discussed in the following sections.

A1-2.1 Scope and Objectives of EPA's Analysis of Harvested Species

The simplicity of EPA's approach to modeling yield was consistent with the need to examine the dozens of harvested species that are vulnerable to I&E at the hundreds of facilities throughout the country that are in scope of the rule and the overall objective of developing regional- and national-scale estimates. This approach is not necessarily the best alternative for studies of single facilities for which site-specific details on local fish stocks and waterbody conditions might make possible the use of more complex assessment approaches (e.g., modeling of population or community level impacts).

A1-2.2 Data Availability and Uncertainties

Although EPA's approach to modeling foregone fishery yield requires estimates of a large number of stage-specific growth and mortality parameters, the use of more complex fish population models would rely on an even larger set of parameters and would require numerous additional and stronger assumptions about the nature of stock dynamics that would be difficult to defend with available data. Additional uncertainties of population dynamics models include the relationship between stock size and recruitment, and how growth and mortality rates may change as a function of stock size and other factors. Obtaining this information for even one fish stock is time-consuming and resource intensive; obtaining this information for the many species subject to I&E nation-wide was not possible for EPA's national benefits analysis because of the resources doing so would require.

It is also important to note that information on stock status (e.g., spawning stock biomass, standardized catch-per-unit-effort, recruitment) is generally only available for harvested species, which represent a minor fraction of I&E losses. Even for harvested species, stock status is often poorly known. In fact, only 23% of U.S. managed fish stocks have been fully assessed (U.S. Ocean Commission, 2002).

In addition to a lack of data, there are numerous issues and difficulties with defining the size and spatial extent of fish stocks. As a result, it is often unclear how I&E losses at particular cooling water intake structures can be related to specific stocks. For example, a recent study of Atlantic menhaden (*Brevoortia tryannus*), one of the major fish species subject to I&E along the Atlantic Coast of the U.S., indicated that juveniles in Delaware Bay result from both local and long distance recruitment (Light and Able, 2003). Thus, accounting only for influences on local recruitment would be insufficient for understanding the relationship between recruitment and menhaden stock size.

Another difficulty is that fisheries managers typically define fish stocks by reference to the geographic scope of the fishery responsible for landings. However, landings data are reported state by state, which is generally not a good way to delineate the true spatial extent of fish populations. These types of delineations create uncertainty in the definition of stocks for the purposes of modeling their population dynamics.

A1-2.3 Difficulties Distinguishing Causes of Population Changes

Another problem in developing and implementing more complex models of harvested species is that it is fundamentally difficult to demonstrate that any particular kind of stress causes a reduction in fish population size. All fish populations are under a variety of stresses that are difficult to quantify given the data currently available and that may interact in a non-additive manner. Fish populations are perpetually in flux for numerous reasons, so determining a baseline population size, then detecting a trend, and then determining if a trend is a significant deviation from an existing baseline or is simply an expected fluctuation around a stable equilibrium is problematic. Fish recruitment is a multidimensional process, and identifying and distinguishing the causes of variance in fish recruitment remains a fundamental problem in fisheries science, stock management, and impact assessment (Hilborn and Walters, 1992; Quinn and Deriso, 1999; Boreman, 2000). Resolving this issue was beyond the scope and objectives of EPA’s section 316(b) benefits analysis.

A1-3 Source Data

The inputs for EPA’s analyses included facility I&E monitoring data collected by facilities with cooling water intake structures and species life history characteristics from the scientific literature such as growth rates, natural mortality rates, and fishing mortality rates.

A1-3.1 Facility Impingement and Entrainment Monitoring Data

The general approach to I&E monitoring was similar at most facilities, but investigators used a wide variety of methods that were specific to the individual studies, e.g., location of sampling stations, sampling gear, sampling frequency, and enumeration techniques. Facilities generally monitored only fish and shellfish species and did not monitor I&E of other types of aquatic organisms. Some facilities monitored only a subset of all fish and shellfish species impinged and entrained.

Impingement monitoring typically involves sampling impingement screens or catchment areas, counting the impinged fish, and extrapolating the count to an annual basis. Entrainment monitoring typically involves intercepting a small portion of the intake flow at a selected location in the facility, collecting fish by sieving the water sample through nets or other collection devices, counting the collected fish, and extrapolating the counts to an annual basis.

EPA retained all information regarding species, life stage, and loss modality (I or E) as they were originally reported by the facilities, with the exception of some species aggregation that is described in section A1-3.2. Facility studies were excluded from EPA’s analysis if the information reported was not suitable for the models used by EPA, which require annual loss rates expressed on a species- and age-specific basis. Studies were also excluded if the study involved sampling at a limited portion of the facility, e.g., at only one of the several intakes, but did not supply sufficient information to conduct a reliable extrapolation from recorded losses to an estimate of total losses (e.g., flow rates at sampled intakes or a description of the reasoning behind the sampling design). In some cases, entrainment sampling was conducted only during the months that larvae are present at a particular facility (usually spring and summer), and in such cases EPA assumed that entrainment rates for these months were indicative of the total annual loss.

In most cases the size or life stage (i.e., age) of impinged fish are not reported. However, the EPA modeling procedure requires the age of the killed fish. Therefore, EPA assumed the age of impinged fish ranged from the juvenile stage to age 5, and divided the total impingement losses into age groups using proportions corresponding to the expected life table dictated by species-specific mortality schedules.

EPA adjusted annualized loss rates at some facilities as needed to reflect the history of technological changes at the facility. The purpose of the adjustments was to interpret loss records in a way that best reflects the current conditions at each facility. For example, if a facility was known to have installed a protective technology subsequent to the time that I&E loss rates were recorded, EPA reduced the loss rates in an amount corresponding to the presumed effectiveness of the protective technology (see the Technical Development Document for the Final Section 316(b) Phase III Existing Facilities Rule).

Loss rates recorded at each facility were expressed as an annual average rate, regardless of the number of years of sampling data available. The annual total among the facilities evaluated was then the subject of the detailed modeling procedure described in section A1-4. Once this analysis was completed, estimates of total losses, by region, were generated using the extrapolation procedures described in section A1-5.

A1-3.2 Species Groups

EPA organized species for which there were limited data into groups and then conducted detailed analyses of I&E rates for each species group. Species groups were based on similarities in life history characteristics and groupings for landings data used by the National Oceanic and Atmospheric Administration (NOAA) Fisheries office (formerly the National Marine Fisheries Service). An appendix to each regional report in Parts B-H of this document provides details on the species, species groups, and life history data that were used.

A1-3.3 Species Life History Parameters

The life history parameters used in EPA's analysis of I&E data included species growth rates, the fraction of each age class vulnerable to harvest, fishing mortality rates, and natural (nonfishing) mortality rates. Each of these parameters was also stage-specific. For the purpose of this assessment, EPA uses the terms "age" and "stage" interchangeably. For fish age 1 and older, a stage corresponds directly to the age in years of the fish. For fish younger than age one, loss data for early life stages were assigned to one of three life stages (eggs, larvae, and juveniles). If the literature provided survival rates of a more detailed staging scheme (e.g., yolk-sac larvae or post-yolk-sac larvae), survival rates were combined to reflect survival for the entire larval life stage.

EPA obtained life history parameters from facility reports, the fisheries literature, local fisheries experts, and publicly available fisheries databases (e.g., FishBase). To the extent feasible, EPA identified region-specific life history parameters. All I&E losses of a particular species or species group within a region were modeled with a single set of parameters. Detailed citations are provided in the life history appendix accompanying each regional report (Parts B-H of the Regional Benefits Assessment).

For most species in most regions a reasonable set of life history parameter values was identified. However, in a few cases where no information on survival rates was available for individual life stages, EPA deduced survival rates for an equilibrium population based on records of lifetime fecundity using the relationship presented in Goodyear (1978) and below in Equation 1:

$$S_{eq} = 2/fa \qquad \text{(Equation 1)}$$

where:

S_{eq} = the probability of survival from egg to the expected age of spawning females
fa = the expected lifetime total egg production

Published fishing mortality rates (F) were assumed to reflect combined mortality due to both commercial and recreational fishing. Basic fishery science relationships (Ricker, 1975) among mortality and survival rates were assumed, such as:

$$Z = M + F \qquad \text{(Equation 2)}$$

where:

Z = the total instantaneous mortality rate
M = natural (nonfishing) instantaneous mortality rate
F = fishing instantaneous mortality rate

and

$$S = e^{(-Z)} \qquad \text{(Equation 3)}$$

where:

S = the survival rate as a fraction

A1-4 Methods for Evaluating I&E

The methods used to express I&E losses in units suitable for economic valuation are outlined in Figure A1-1 and described in detail in the following sections.

A1-4.1 Modeling Age-1 Equivalents

The Equivalent Adult Model (EAM) is a method for expressing I&E losses as an equivalent number of individuals at some other life stage, referred to as the age of equivalency (Horst, 1975; Goodyear, 1978; Dixon, 1999). The age of equivalency can be any life stage of interest. The method provides a convenient means of converting losses of fish eggs and larvae into units of individual fish and provides a standard metric for comparing losses among species, years, and regions. For the Regional Benefits Assessment, EPA expressed I&E losses at all life stages as an equivalent number of age-1 year individuals.

The EAM calculation for each species requires life-stage-specific I&E counts and life-stage-specific mortality rates from the life stage of I&E to the life stage of equivalence (age 1 year, for this assessment). The cumulative survival rate from age at impingement or entrainment until age 1 is the product of all stage-specific survival rates to age 1. For impinged fish that are older than age 1, age-1 equivalents are calculated by modifying the basic calculation to inflate the loss rates in inverse proportion to survival rates. In the case of entrainment, the basic calculation is:

$$S_{j,1} = S_j^* \prod_{i=j+1}^{j_{\max}} S_i \qquad \text{(Equation 4)}$$

where:

$S_{j,1}$ = cumulative survival from stage *j* until age 1
S^*_j = $2S_j e^{-\log(1+Sj)}$ = adjusted S_j
$j_{\max}$ = the stage immediately prior to age 1
S_i = survival fraction from stage *i* to stage *i* + 1

Equation 4 defines $S_{j,1}$, which is the expected cumulative survival rate (as a fraction) from the stage at which entrainment occurs, *j*, through age 1. The components of Equation 4 represent survival rates during the different life stages between life stage *j*, when a fish is entrained, and age 1. Survival through the stage at which entrainment occurs, *j*, is treated as a special case because the amount of time spent in that stage before entrainment is unknown and therefore the known stage specific survival rate, S_j, does not apply because S_j describes the survival rate through the entire length of time that a fish is in stage *j*. Therefore, to find the expected survival rate from the day that a fish was entrained until the time that it would have passed into the subsequent stage, an adjustment to S_j is required. The adjusted rate S^*_j describes the effective survival rate for the group of fish entrained at stage *j*, considering the fact that the individual fish were entrained at various specific ages within stage *j*.

Age-1 equivalents are then calculated as:

$$AE1_{j,k} = L_{j,k}\, S_{j,1} \qquad \text{(Equation 5)}$$

where:

$AE1_{j,k}$ = the number of age-1 equivalents killed during life stage *j* in year *k*
$L_{j,k}$ = the number of individuals killed during life stage *j* in year *k*
$S_{j,1}$ = the cumulative survival rate for individuals passing from life stage *j* to age 1

The total number of age-1 equivalents derived from losses at all stages in year *k* is then given by:

$$AE1_k = \sum_{j=j_{\min}}^{j_{\max}} AE1_{j,k} \qquad \text{(Equation 6)}$$

where:

$AE1_k$ = the total number of age-1 equivalents derived from losses at all stages in year *k*

A1-4.2 Modeling Foregone Fishery Yield

Foregone fishery yield is a measure of the amount of fish or shellfish (in pounds) that is not harvested because the fish are lost to I&E. EPA estimated foregone yield using the Thompson-Bell equilibrium yield model (Ricker, 1975). The model provides a simple method for evaluating a cohort of fish that enters a fishery in terms of their fate as harvested or not-harvested individuals. EPA's application of the Thompson-Bell model assumes that I&E losses result in a reduction in the number of harvestable adults in years after the time that individual fish are killed by I&E and that future reductions in I&E will lead to future increases in fish harvest.

The Thompson-Bell model is based on the same general principles that are used to estimate the expected yield in any harvested fish population (Hilborn and Walters, 1992; Quinn and Deriso, 1999). The general procedure involves multiplying age-specific harvest rates by age-specific weights to calculate an age-specific expected yield (in pounds). The lifetime expected yield for a cohort of fish is then the sum of all age-specific expected yields, thus:

$$Y_k = \sum_j \sum_a L_{jk} S_{ja} W_a (F_a / Z_a) \qquad \text{(Equation 7)}$$

where:

Y_k = foregone yield (pounds) due to I
L_{jk} = losses of individual fish of stage j in the year k
S_{ja} = cumulative survival fraction fr
W_a = average weight (pounds) of fish at age a
F_a = instantaneous annual fishing mortality r
Z_a = instantaneous annual total mortality r

The model assumes that:

- the yield from a cohort of fish is proportional to the number recruited;
- annual growth, natural mortality, and fishing mortality rates are known and constant; and
- natural mortality includes mortality due to I&E.

The assumption that fishing mortality, *F*, remains constant despite possible reductions in I&E is central to the modeling approach used to estimate changes in fishery yield. This assumption implies that fishing activity and fishing regulations will adapt to increases in fish stock in a manner that leads to harvest increases in direct proportion to the magnitude of increases in harvestable stock.

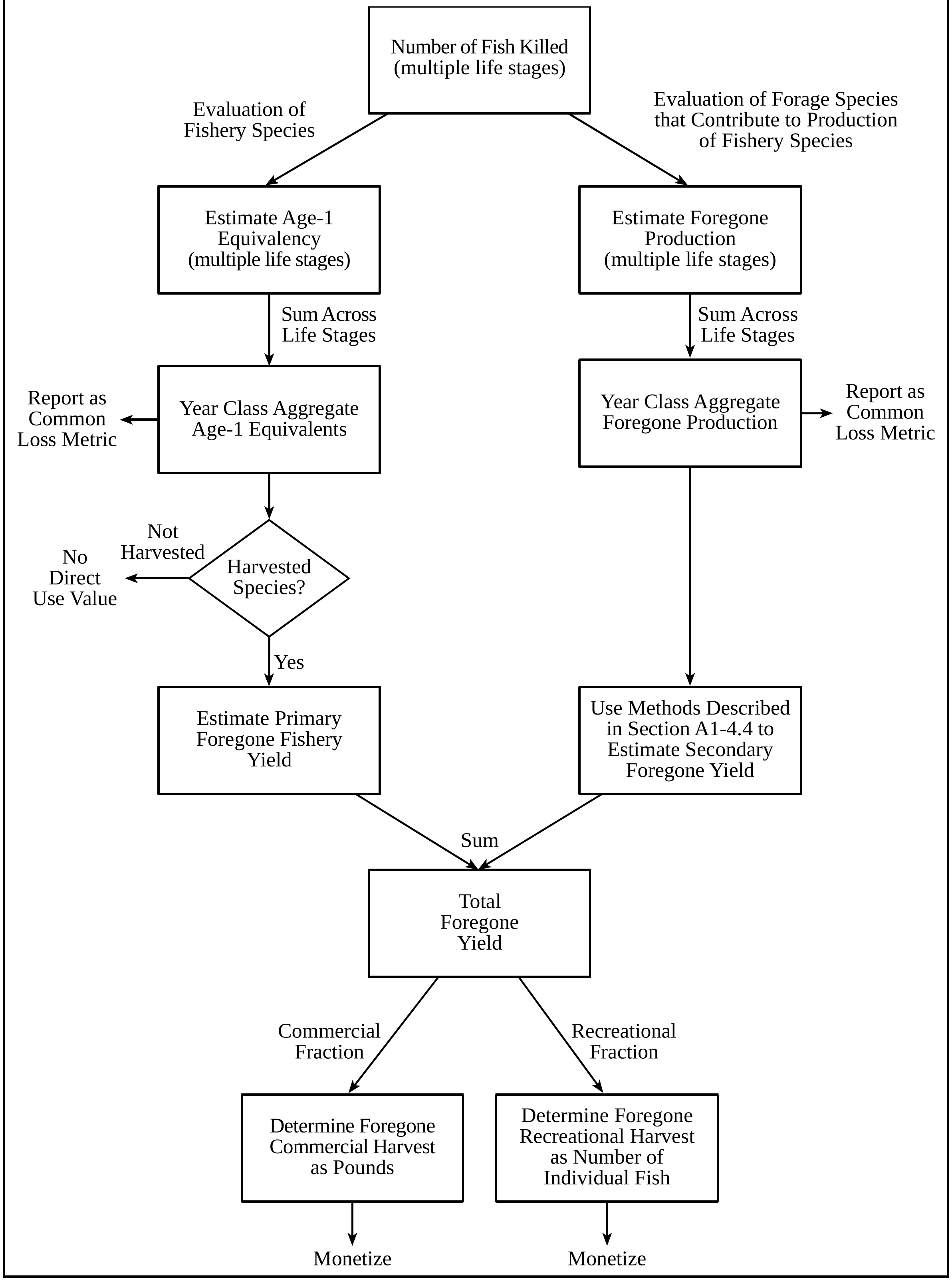
The assumption that *M* and *F* are constant is based on EPA's assumptions that:

- I&E losses are a relatively minor source of mortality in comparison to the total effect of all other sources of natural mortality (e.g., predation); and
- the scale of changes in I&E loss rates being considered will not lead to dramatically large increases in the size of harvestable stocks.

EPA acknowledges that in some cases the importance of I&E as a source of mortality in a fishery might be large enough that it would be unlikely that natural and fishing mortality would remain constant, but such cases are not expected to be the norm.

As indicated in Figure A1-1, EPA partitioned its estimates of total foregone yield for each species into two classes, foregone recreational yield and foregone commercial yield, based on the relative proportions of recreational and commercial state-wide aggregate catch rates of that species in that region. Pounds of foregone yield to the recreational fishery were re-expressed as numbers of individual fish based on the expected weight of an individual harvestable fish. Chapter A3 describes the methods used to derive dollar values for foregone commercial and recreational yields for the Regional Benefits Assessment.

Figure A1-1: General Approach Used to Evaluate I&E Losses as Foregone Fishery Yield



A1-4.3 Modeling Production Foregone

In addition to expressing I&E losses as lost age-1 equivalents (and subsequent lost yield, for harvested species), I&E losses were also expressed as foregone production. Foregone production is the expected total amount of future growth (expressed as pounds) of individuals that were impinged or entrained, had they not been impinged or entrained (Rago, 1984). Production foregone estimates are used in EPA's analysis to calculate the contribution of forage species lost to I&E to foregone fishery yield, as discussed in section A1-4.4.

Production foregone is calculated by simultaneously considering the stage-specific growth increments and survival probabilities of individuals lost to I&E, where production includes the biomass accumulated by individuals alive at the end of a time interval as well as the biomass of those individuals that died before the end of the time interval. Thus, the production foregone for a specified stage, *i*, is calculated as:

$$P_i = \frac{G_i N_i W_i \left(e^{(G_i - Z_i)} - 1\right)}{G_i - Z_i} \qquad \text{(Equation 8)}$$

where:

P_i = expected production (pounds) for an individual during stage *i*
G_i = the instantaneous growth rate for individuals of stage *i*
N_i = the number of individuals of stage *i* lost to I&E (expressed as equivalent losses at subsequent stages)
W_i = average weight (in pounds) for individuals of stage *i*
Z_i = the instantaneous total mortality rate for individuals of stage *i*

P_j, the production foregone for all fish lost at stage *j*, is calculated as:

$$P_j = \sum_{i=j}^{t_{\max}} P_{ji} \qquad \text{(Equation 9)}$$

where:

P_j = the production foregone for all fish lost at stage
$t_{\max}$ = oldest stage considered

P_T, the total production foregone for fish lost at all stages *j*, is calculated as:

$$P_T = \sum_{j=t_{\min}}^{t_{\max}} P_j \qquad \text{(Equation 10)}$$

where:

P_T = the total production foregone for fish lost at all stages *j*
$t_{\min}$ = youngest stage considered

A1-4.4 Evaluation of Forage Species Losses

I&E losses of forage species (i.e., species that are not targets of recreational or commercial fisheries) have both immediate and future impacts because not only is existing biomass removed from the ecosystem, but also the biomass that would have been produced in the future is no longer available as food for predators (Rago, 1984; Summers, 1989). The Production Foregone Model described in the previous section accounts for these consequences of I&E losses by considering the biomass that would have been transferred to other trophic levels but for the removal of organisms by I&E (Rago, 1984; Dixon, 1999). Consideration of the future impacts of current losses is particularly important for fish, since there can be a substantial time between loss and replacement, depending on factors such as spawning frequency and growth rates (Rago, 1984).

To evaluate I&E losses of forage species for the purposes of the benefits analysis, EPA translated forage species production foregone into foregone yield of harvested species that are known to be impinged and entrained using a simple trophic transfer model. These estimates of the foregone yield of impinged and entrained harvested species are distinct from the primary foregone yield of these species and are termed “secondary yield” or “trophic transfer.” This procedure is presented in Equations 11 and 12, and illustrated schematically in Figure A1-2.

The basic assumption behind EPA’s approach to evaluating losses of forage species is that a decrease in the production of forage species can be related to a decrease in the production of impinged and entrained harvested (predator) species based on an estimate of trophic transfer efficiency. Thus, in general,

$$P_h = k\, P_f \qquad \text{(Equation 11)}$$

where:

P_h = foregone biomass production of a harvested species h (in pou
k = the trophic transfer efficiency
P_f = foregone biomass production of a forage species f (in pou

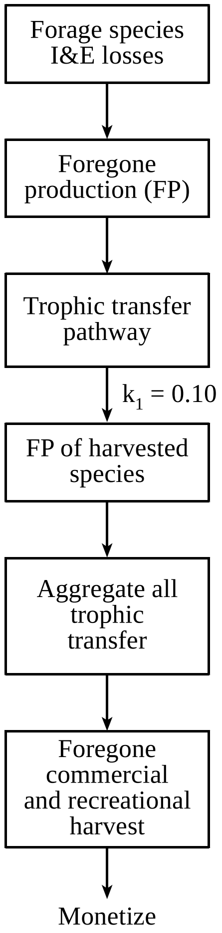
Equation 11 is applicable to trophic transfer on a species-to-species basis where one species is strictly prey and the other species is strictly a predator. For the section 316(b) Regional Benefits Assessment, commercially or recreationally valuable fish were considered predators. The aggregate total secondary yield or trophic transfer is estimated on a regional basis under the assumption that the trophic value of total foregone production among forage species is allocated equally among all harvested species that occur in the I&E losses, thus:

$$Y_{\mathrm{sec}} = \sum_{\substack{h\,\in all\\ harvested\\ species}} \left(\frac{k}{H} \sum_{\substack{f\,\in all\\ forage\\ species}} P_f \right) \left({}^{Y_h}\!\big/_{P_h} \right) \qquad \text{(Equation 12)}$$

where:

Y_{sec} = total secondary yield (as a generic predator species)
H = number of harvested species among regional loss estimates
Y_h = primary estimate of foregone yield for harvested species h
P_h = estimate of foregone production for harvested species h

Figure A1-2: Trophic Transfer Model



It is difficult to determine, on a community basis, an appropriate value of *k* that relates aggregate forage production and aggregate predator production, since the actual trophic pathways are complicated. For the purposes of its 316(b) analysis, EPA used the value of $k = 0.10$ based on a review of the available literature by Pauly and Christensen (1995).

EPA would like to stress that this model of trophic transfer is a very simple and idealized representation of trophic dynamics. The purpose of the model is to provide a national-scale approximation of foregone yield for EPA's 316(b) rulemaking. It is not intended to capture the actual details of trophic transfer in specific waterbodies affected by I&E. It is important to recognize that, in reality, food webs and trophic transfer dynamics are much more complex than this simple model implies, and include details that are specific to each particular aquatic ecosystem and community of species.

A1-5 Extrapolation of I&E Rates

EPA examined I&E losses and the economic benefits of reducing these losses at the regional scale. The estimated benefits were then aggregated across all regions to yield a national benefits estimate. These regions and the waterbody types within each region are described in the Introduction to this Regional Benefits Assessment. Maps showing the facilities in each region that are in scope of the section 316(b) rulemaking process for Phase III existing facilities are provided in the introductory chapter of each regional report (Parts B-H of this document).

To obtain regional I&E estimates, EPA extrapolated losses observed at the facilities evaluated (facilities with suitable records of I&E rates) to other in-scope facilities within the same region. Extrapolation of I&E rates from these "model" facilities was necessary because not all in scope facilities within a given region have conducted I&E studies. Model facilities included both Phase II and Phase III facilities, based on the assumption that I&E rates at Phase II and Phase III facilities are similar after normalization by intake flow. Phase II facilities were included to make use of the largest possible data set and to accommodate the lack of Phase III facility I&E studies in some regions (see Table A1-1).

Table A1-1: Number of Model Facilities, by Region and Phase of Rulemaking

Region	Phase II	Phase III
California	18	0
North Atlantic	4	2
Mid-Atlantic	10	2
Gulf of Mexico	4	0
Great Lakes	8	3
Inland	30	13
South Atlantic	2	0

I&E data were extrapolated on the basis of operational flow, in millions of gallons per day (MGD), where MGD is the average operational flow over the period 1996-1998 as reported by facilities in response to EPA's *Section 316(b) Detailed Questionnaire and Short Technical Questionnaire*. Operational flow at each facility was rescaled using factors reflecting the relative effectiveness of currently in-place technologies for reducing I&E. Thus, to reflect entrainment technology in place at a facility:

$$F_{f,e} = G_f\,(1-T_{f,e}) \qquad \text{(Equation 13)}$$

where:

$F_{f,e}$ = effective relative flow rate for entrainment at facility f
G_f = mean operational flow at facility f (10^6 gallons/day)
$T_{f,e}$ = fractional effectiveness of entrainment-reducing technology at facility f ($0<T_{f,e}<1$)

To reflect impingement technology in place at a facility:

$$F_{f,i} = G_f\,(1-T_{f,i}) \qquad \text{(Equation 14)}$$

where:

$F_{f,i}$ = effective relative flow rate for impingement at facility f
G_f = mean operational flow at facility f (10^6 gallons/day)
$T_{f,i}$ = fractional effectiveness of impingement-reducing technology at facility f ($0<T_{f,i}<1$)

Next, regional estimates were developed as outlined in Equations 15-18. Statistical weighting factors (from EPA's survey of the industry) were multiplied by flow rates at each facility prior to estimating the total regional flow rate. To scale estimates for entrainment losses:

$$S_{r,e} = \sum_{\substack{f \in \text{All facilities} \\ \text{in region r}}} J_f \; F_{f,e} \Bigg/ \sum_{\substack{f \in \text{All model facilities} \\ \text{in region r}}} F_{f,e} \qquad \text{(Equation 15)}$$

where:

$S_{r,e}$ = scaling factor to relate total entrainment losses among model facilities to regional total entrainment losses
J_f = statistical weighting factor for facility *f*
$F_{f,e}$ = effective relative flow rate for entrainment at facility *f*

To scale estimates for impingement losses:

$$S_{r,i} = \sum_{\substack{f \in \text{All facilities} \\ \text{in region r}}} J_f \; F_{f,i} \Bigg/ \sum_{\substack{f \in \text{All model facilities} \\ \text{in region r}}} F_{f,i} \qquad \text{(Equation 16)}$$

where:

$S_{r,i}$ = scaling factor to relate total impingement losses among model facilities to regional total impingement losses
J_f = statistical weighting factor for facility *f*
$F_{f,i}$ = effective relative flow rate for impingement at facility *f*

To estimate total entrainment losses for a region:

$$L_{r,e} = S_{r,e} \sum_{\substack{f \in \text{All model facilities} \\ \text{in region r}}} L_{f,e} \qquad \text{(Equation 17)}$$

where:

$L_{r,e}$ = estimated annual total entrainment losses at region *r*
$S_{r,e}$ = scaling factor to relate total entrainment losses among model facilities to regional total entrainment losses
$L_{f,e}$ = estimated annual total entrainment losses at facility *f*

To estimate total impingement losses for a region:

$$L_{r,i} = S_{r,i} \sum_{\substack{f \in \text{All model facilities} \\ \text{in region r}}} L_{f,i} \qquad \text{(Equation 18)}$$

where:

$L_{r,i}$ = estimated annual total impingement losses at region *r*
$S_{r,i}$ = scaling factor to relate total impingement losses among model facilities to regional total impingement losses
$L_{f,i}$ = estimated annual total impingement losses at facility *f*

EPA recognizes that there may be substantial among-facility variation in the actual I&E losses per MGD resulting from a variety of facility-specific features, such as location and type of intake structure, as well as from ecological features that affect the abundance or species composition of fish in the vicinity of each facility. The accuracy of EPA's extrapolation procedure relies heavily on the assumption that I&E rates recorded at model facilities are representative of I&E rates at other facilities in the region. Although this assumption may not be met in some cases, limiting the extrapolation procedure to particular regions reduces the likelihood that the model facilities are unrepresentative.

EPA believes that this method of extrapolation makes best use of a limited amount of empirical data, and is the only currently feasible approach for developing an estimate of national I&E and the benefits of reducing I&E. While acknowledging that an extrapolation necessarily introduces additional uncertainty into I&E estimates, EPA has not identified information that suggests that application of the procedure causes a systematic bias in the regional loss estimates.

The assumption that I&E is proportional to flow is consistent with other predictive I&E studies. For example, a key assumption of the Spawning and Nursery Area of Consequence (SNAC) model (Polgar et al., 1979) is that entrainment is proportional to cooling water withdrawal rates. The SNAC model has been used as a screening tool for assessing potential I&E impacts at Chesapeake Bay plants. As a first approximation, percent entrainment has been predicted on the basis of the ratio of cooling water flow to source water flow (e.g., Goodyear, 1978). A study of power plants on the Great Lakes (Kelso and Milburn, 1979) demonstrated an increasing relationship (on a log-log scale) between plant "size" (electric production in MWe) and I&E. There is scatter in these relationships, not just because there is variation in the cooling water intake for different plants having similar electric production, but also because of the imprecision (sampling variability) inherent in the usual methods of estimating I&E. These relationships are nonetheless strong.

Chapter A2: Uncertainty

Introduction

This chapter discusses sources of uncertainty in EPA's impingement and entrainment (I&E) analyses, and presents the results of an uncertainty analysis of the yield model used by EPA to estimate the benefits of reducing I&E of commercial and recreational fishery species. Section A2-1 discusses major uncertainties in EPA's I&E assessments, section A2-2 briefly describes Monte Carlo analysis as a tool for quantifying uncertainty, section A2-3 provides preliminary results of an uncertainty analysis by EPA of winter flounder yield estimates, and section A2-4 discusses results of the uncertainty analysis.

Chapter Contents

A2-1 Types of Uncertainty....................................A2-1
  A2-1.1 Structural Uncertainty A2-1
  A2-1.2 Parameter Uncertainty.....................A2-2
  A2-1.3 Uncertainties Related to Engineering A2-4
A2-2 Monte Carlo Analysis as a Tool for Quantifying Uncertainty A2-4
A2-3 EPA's Uncertainty Analysis of Yield Estimates..A2-4
  A2-3.1 Overview of Analysis......................A2-4
  A2-3.2 Results A2-5
A2-4 Conclusions..A2-6

A2-1 Types of Uncertainty

Despite following sound scientific practice throughout, it was impossible to avoid several sources of uncertainty that may cause EPA's I&E estimates in the regional analysis to be imprecise or to carry potential statistical bias. Uncertainty of this nature is not unique to EPA's I&E analysis.

Uncertainty may be classified into two general types (Finkel, 1990). One type, referred to as structural uncertainty, reflects the limits of the conceptual formulation of a model and relationships among model parameters. The other general type is parameter uncertainty, which flows from uncertainty about any of the specific numeric values of model parameters. The following discussion considers these two types of uncertainty in relation to EPA's I&E analysis.

A2-1.1 Structural Uncertainty

The models used by EPA to evaluate I&E simplify a very complex process. The degree of simplification is substantial but necessary because of the limited availability of empirical data. Table A2-1 provides examples of some considerations that are not captured by the models used.

Table A2-1: Uncertainties Associated with Model Structure

Type	General Treatment in Model	Specific Treatment in Model
Generally simple structure	Species lost to I&E treated independently	Fish species grouped into two categories: harvested or not harvested (forage for harvested species).
Biological submodels	No dynamic elements	Life history parameters constant (i.e., growth and survival did not vary through time); growth and survival rates did not change in response to possible compensatory effects.

A2-1.2 Parameter Uncertainty

Uncertainty about the numeric values of model parameters arises for two general reasons. The first source of parameter uncertainty is imperfect precision and accuracy of I&E data reported by facilities and growth and mortality rates obtained from the scientific literature. This results from unavoidable sampling and measurement errors. The second major source of parameter uncertainty is the applicability of parameter estimates obtained from I&E or life history studies conducted at other locations or under different conditions.

EPA’s review of available facility impingement and entrainment studies identified a number of study design limitations that can increase uncertainty about impingement mortality and entrainment estimates, including data collection for only one to two years or limited to one season or for a subset of the affected species; limited taxonomic detail (i.e., often egg and larval losses are not identified to the species level); and a general lack of standard methods and metrics for quantifying impingement mortality and entrainment. Further, in many cases it is likely that f the state of the waterbody itself has changed since these studies were conducted.

Table A2-2 presents some examples of parameter uncertainty. In all of these cases, increasing uncertainty about specific parameters implies increasing uncertainty about EPA’s point estimates of I&E losses. The point estimates are biased only insofar as the input parameters are biased in aggregate (i.e., inaccuracies in multiple parameter values that are above the “actual” values but below the “actual” values in other cases may tend to counteract). In this context, EPA believes that parameter uncertainty will generally lead to imprecision, rather than inaccuracies, in the final results.

Table A2-2: Parameters Included in EPA's I&E Analysis that are Subject to Uncertainty

Type	Factors	Examples of Uncertainties in Model
I&E monitoring /loss rate estimates	Sampling regimes	Sampling regimes subject to numerous plant-specific details; no established guidelines or performance standards for how to design and conduct sampling regimes.
	Extrapolation assumptions	Extrapolation of monitoring data to annual I&E rates requires numerous assumptions regarding diurnal/seasonal/annual cycles in fish presence and vulnerability and various technical factors (e.g., net collection efficiency; hydrological factors affecting I&E rates); no established guidelines or consistency in sampling regimes.
	Species selection	Criteria for selection of species to evaluate not well-defined or uniform across facilities. I&E data collected for only a subset of species, usually only fish and shellfish.
	Sensitivity of fish to I&E	Through-plant entrainment mortality assumed by EPA to be 100%; some back-calculations done in cases where facilities had reported entrainment rates that assumed <100% mortality. Impingement survival included if presented in facility documents.
Biological/life history	Natural mortality rates	Natural mortality rates (M) difficult to estimate; model results highly sensitive to M.
	Growth rates	Simple exponential growth rates or simple size-at-age parameters used.
	Geographic considerations	Migration patterns; I&E occurring during spawning runs or larval out-migration; location of harvestable adults; intermingling with other stocks.
	Forage valuation	Harvested species assumed to be food limited; trophic transfer efficiency to harvested species estimated by EPA based on general models; no consideration of trophic transfer to species not impinged and entrained.
Stock characteristics	Fishery yield	For harvest species, used only one species-specific value for fishing mortality rate (F) for all stages subject to harvest; used stage-specific constants for fraction vulnerable to fishery.
	Harvest behavior	No assumed dynamics among harvesters to alter fishing rates or preferences in response to changes in stock size; recreational access assumed constant (no changes in angler preferences or effort).
	Stock interactions	I&E losses assumed to be part of reported fishery yield rates on a statewide basis; no consideration of possible substock harvest rates or interactions.
Ecological System	Fish community	Long-term trends in fish community composition or abundance not considered (general food webs assumed to be static); used constant value for trophic transfer efficiency; specific trophic interactions not considered. Trophic transfer to organisms not impinged and entrained is not considered.
	Spawning dynamics	Sampled years assumed to be typical with respect to choice of spawning areas and timing of migrations that could affect vulnerability to I&E (e.g., presence of larvae in vicinity of intake structure).
	Hydrology	Sampled years assumed to be typical with respect to flow regimes and tidal cycles that could affect vulnerability to I&E (e.g., presence of larvae in vicinity of CWIS).
	Meteorology	Sampled years assumed to be typical with respect to vulnerability to I&E (e.g., presence of larvae in vicinity of intake structure).

A2-1.3 Uncertainties Related to Engineering

EPA's evaluation of I&E was also affected by uncertainty about the engineering and operating characteristics of the study facilities. It is unlikely that plant operating characteristics (e.g., seasonal, diurnal, or intermittent changes in intake water flow rates) were constant throughout any particular year, which therefore introduces the possibility of bias in the loss rates reported by the facilities. EPA assumed that the facilities' loss estimates were provided in good faith and did not include any biases or omissions that significantly modified loss estimates.

A2-2 Monte Carlo Analysis as a Tool for Quantifying Uncertainty

Stochastic simulation is among a class of statistical procedures commonly known as Monte Carlo modeling methods. Monte Carlo methods allow investigators to quantify uncertainty in model results based on knowledge or assumptions about the amount of uncertainty in each of the various input parameters. The Monte Carlo approach also allows investigators to conduct sensitivity analyses to elucidate the relative contribution of the uncertainty in each input parameter to overall uncertainty. Monte Carlo methods are particularly useful for assessing models where analytic (i.e., purely mathematical) methods are cumbersome or otherwise unsuitable. A thorough introduction to the statistical reasoning that underlies Monte Carlo methods, and their application in risk assessment frameworks, is provided in an EPA document "Guiding Principles for Monte Carlo Analysis" (U.S. EPA, 1997).

The characteristic feature of Monte Carlo methods is the generation of artificial variance through the use of pseudorandom numbers. The solution to the model of interest is recalculated many times, each time adding perturbations to the values of the model parameters. The types of perturbations are selected to reflect the actual uncertainty in knowledge of those parameters. Recalculations are conducted thousands of times, and the variation in the resulting solution is assessed and interpreted as an indicator of the aggregate uncertainty in the basic result.

A2-3 EPA's Uncertainty Analysis of Yield Estimates

A2-3.1 Overview of Analysis

As described in detail in Chapter A1 of this report, EPA estimated foregone yield using the Thompson-Bell equilibrium yield model (Ricker, 1975). The Thompson-Bell model is based on the same general principles that are used to estimate the expected yield in any harvested fish population (Hilborn and Walters, 1992; Quinn and Deriso, 1999). The general procedure involves multiplying age-specific weights by age-specific harvest rates to calculate an age-specific expected yield (in pounds). The lifetime expected yield for a cohort of fish is then the sum of all age-specific expected yields.

$$Y_k = \sum_j \sum_a L_{jk} S_{ja} W_a (F_a / Z_a)\left(1 - e^{-Z_a}\right) \qquad \text{(Equation 1)}$$

where:

Y_k = foregone yield (pounds) due to I&E losses in year *k*
L_{jk} = losses of individual fish of stage *j* in the year *k*
S_{ja} = cumulative survival fraction from stage *j* to age *a*
W_a = average weight (pounds) of fish at age *a*
F_a = instantaneous annual fishing mortality rate for fish of age *a*
Z_a = instantaneous annual total mortality rate for fish of age *a*

Quantifying the variance in yield estimates resulting from uncertainty in the numeric values of *L*, *S*, *W*, *F*, and *Z* assists in the interpretation of results, gives a sense of the precision in yield estimates, provides insight into the sensitivity of predictions to particular parameter values, and indicates the contribution of particular parameters to overall uncertainty.

EPA evaluated uncertainty in yield estimates for winter flounder using I&E data for a facility located on a North Atlantic estuary. The I&E loss records and winter flounder life history parameters that were used are provided in the Phase II docket as DCN #4-2037.

EPA developed a custom program written in the S language to conduct the Monte Carlo analysis. Wherever possible, the simulation tool re-used the same code that was used to calculate yield for the original assessment. Graphical displays were used to confirm the behavior of random number generation and to examine results.

Selection of input distributions for parameters of interest are a key element of any Monte Carlo analysis. In the winter flounder test case, the parameter values were drawn from uniform distributions with a range defined as the initial, best estimate of the parameter +/- 15%.

EPA investigated sensitivity of the model to variations in parameters by grouping the parameters into five classes:

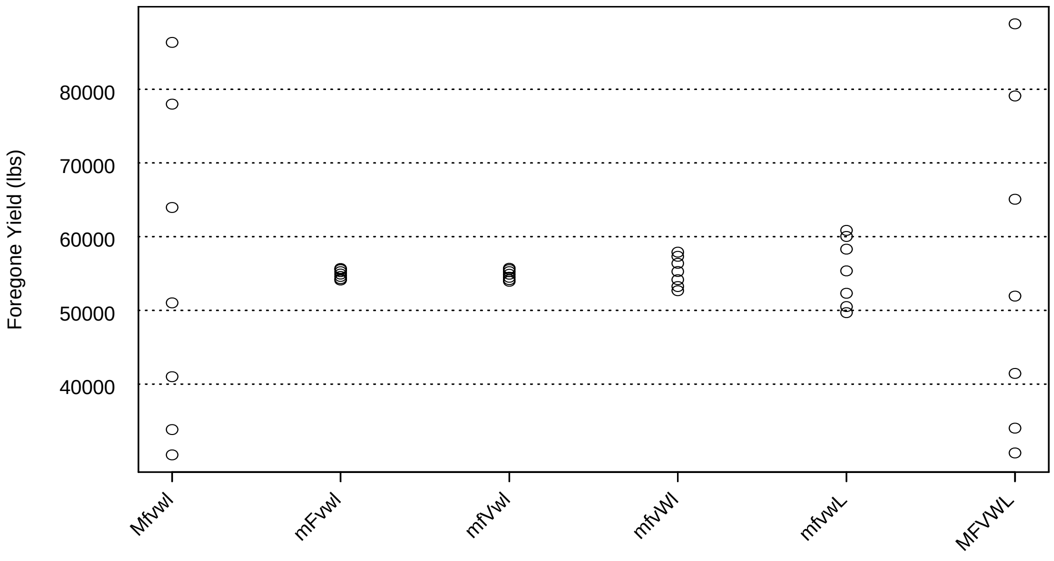
- natural mortality (*M*) at all life stages;
- fishing mortality (*F*) at all life stages;
- fraction vulnerable to fishing (*V*) at all life stages (i.e., age of recruitment to the fishery);
- weight at age (*W*); and
- the reported I&E loss rates (*L*).

The analysis consisted of repeating runs (n = 10,000 in each run) of the model wherein each of the groups of parameters was either held constant at their best estimates or were varied stochastically according to the defined input distributions. The relative importance of these groups of parameters was assessed by comparing the relative amount of variation between each set of runs. Model sensitivity to individual parameters has not been examined.

A2-3.2 Results

For entrainment losses for this species, the analysis indicated that the yield model is most sensitive to uncertainty in natural mortality rates, followed by uncertainty in the I&E loss rates themselves (Figure A2-1). Age-specific weights were the third most important group, followed by fishing mortality and age at recruitment, which were relatively insignificant sources of uncertainty.

Figure A2-1: Results of Parameter Sensitivity Analysis of Estimates of Foregone Yield (pounds) of Winter Flounder due to Entrainment by a Power Plant Located in a North Atlantic Estuary



Data points are plotted at the 5th percentile, 10th percentile, 25th percentile, median, 75th percentile, 90th percentile, and 95th percentile of 10,000 independent estimates of foregone yield within each parameter set. Groups are distinguished by uppercase letters designating which types of parameters were treated stochastically in the simulation and lowercase letters for types of parameters fixed at their best estimates. M = natural mortality rates; F = fishing mortality rates; V = age of recruitment to the fishery; W = weight at age; L = entrainment loss rates.

A2-4 Conclusions

This chapter includes a general discussion of uncertainty and describes a general approach that was tested by EPA as a way to quantify uncertainty associated with the yield model described in Chapter A1. Preliminary results of the uncertainty analysis suggest that uncertainty about natural mortality rates is a significant contributor to aggregate uncertainty in yield estimates. Unfortunately, as noted in a review article by Vetter (1988), “True rates of natural mortality, and their variability, are poorly known for even the great stocks of commercial fish in temperate regions that have been subject to continuous exploitation for decades” (Vetter, 1988, p. 39). As a result, the uncertainty in mortality parameters cannot be overcome. As Vetter (1988) noted, this is a difficulty shared by all models of fish stock dynamics. Nonetheless, through consultation with local fish biologists as well as the scientific literature, EPA expended considerable effort to identify reasonable mortality rates and other life history information for use in its yield analyses. These parameter values and data sources are presented in Appendix 1 of each regional report (Parts B-H of this document).

Chapter A3: Economic Benefit Categories and Valuation

Chapter Contents

A3-1 Economic Benefit Categories Applicable to the Regulatory Analysis Options for Phase III Facilities A3-2
A3-2 Direct Use Benefits.................................. A3-5
A3-3 Indirect Use Benefits A3-7
A3-4 Non-Use Benefits A3-7
  A3-4.1 Role of Non-Use Benefits in the Benefits Analysis for the Regulatory Analysis Options for Phase III Facilities A3-8
A3-5 Summary of Benefit Categories A3-9
A3-6 Causality: Linking the Regulatory Analysis Options for Phase III Existing Facilities to Beneficial Outcomes........... A3-11
A3-7 Conclusions A3-12

Introduction

Changes in cooling water intake structure (CWIS) design or operations resulting from the regulatory analysis options for the final section 316(b) rule for Phase III facilities were expected to reduce impingement and entrainment (I&E) losses of fish, shellfish, and other aquatic organisms. As a result, the regulatory analysis options were expected to increase the numbers of individuals present and increase local and regional fishery populations.

The aquatic resources affected by cooling water intake structures provide a wide range of ecosystem services. Ecosystem services are the physical, chemical, and biological functions performed by natural resources and the human benefits derived from those functions, including both ecological and human use services (Daily, 1997; Daily et al., 1997). Scientific and public interest in protecting ecosystem services is increasing with the recognition that these services are vulnerable to a wide range of human activities and are difficult, if not impossible, to replace with human technologies (Meffe, 1992).

In addition to their importance in providing food and other goods of direct use to humans, the organisms lost to I&E are critical to the continued functioning of the ecosystems of which they are a part. Fish are essential for energy transfer in aquatic food webs, regulation of food web structure, nutrient cycling, maintenance of sediment processes, redistribution of bottom substrates, the regulation of carbon fluxes from water to the atmosphere, and the maintenance of aquatic biodiversity (Peterson and Lubchenco, 1997; Postel and Carpenter, 1997; Holmlund and Hammer, 1999; Wilson and Carpenter, 1999). Examples of the impact of I&E on ecological and public services include:

- decreased numbers of ecological keystone, rare, or sensitive species;
- decreased numbers of popular species that are not fished, perhaps because the fishery is closed;
- decreased numbers of special status (e.g., threatened or endangered) species;
- increased numbers of exotic or disruptive species that compete well in the absence of species lost to I&E;
- disruption of ecological niches and ecological strategies used by aquatic species;
- disruption of organic carbon and nutrient transfer through the food web;
- disruption of energy transfer through the food web;
- decreased local biodiversity;
- disruption of predator-prey relationships;
- disruption of age class structures of species;
- disruption of natural succession processes;
- disruption of public uses other than fishing, such as diving, boating, and nature viewing; and
- disruption of public satisfaction with a healthy ecosystem.

Many of these services can only be maintained by the continued presence of all life stages of fish and other aquatic species in their natural habitats.

The traditional approach of EPA and other natural resource agencies to quantifying the environmental benefits of regulations has focused on active use values, particularly direct use values such as recreational or commercial fishing. Nonconsumptive uses (such as the importance of fish for aquatic food webs), and passive use or non-use values (including the value of protecting a resource for its own sake), are seldom separately quantified because they are difficult to monetize with available economic methods. However, even though economists debate methods for indirect and non-use valuation, there is general agreement that these values exist and can be important (Freeman, 2003). When valuations that include both use and non-use components, such as Carson and Mitchell (1993), and Mitchell and Carson (1981, 1986, and 1989) are used, non-use values are incorporated into the analysis, although they cannot be separated from use values.

This chapter first identifies the types of economic benefits that are likely to be generated by improved ecosystem functioning resulting from the regulatory analysis options for Phase III facilities. Then, the chapter presents the basic economic concepts regarding economic benefits, including benefit categories and benefit taxonomies associated with market and nonmarket goods and services that are likely to flow from reduced I&E. Other chapters in this section of the report detail the methods used to estimate values for reductions in I&E. These methods are in turn applied in the regional studies described in Parts B through H of this document.

A3-1 Economic Benefit Categories Applicable to the Regulatory Analysis Options for Phase III Facilities

The term “economic benefits” for our purposes refers to the dollar value associated with all of the expected positive impacts of the regulatory analysis options for Phase III facilities. The basic approach for estimating the benefits of a policy event is to evaluate changes in social welfare realized by consumers and producers. Such measures are based on standardized and widely accepted concepts within applied welfare economics. They reflect the degree of well-being derived by economic agents (e.g., people and/or firms) given different levels of goods and services, including those associated with environmental quality. For market goods, analysts typically use money-denominated measures of consumer and producer surplus, which provide an approximation of exact welfare effects (Freeman, 2003).[1] For nonmarket goods, such as aquatic habitat, values must be assessed using nonmarket valuation methods. In such cases, valuation estimates are typically restricted to effects on individual households (or consumers), and either represent consumer surplus or analogous exact Hicksian welfare measures (e.g., compensating surplus). The choice of welfare (i.e., value) measures is often determined by the valuation context.

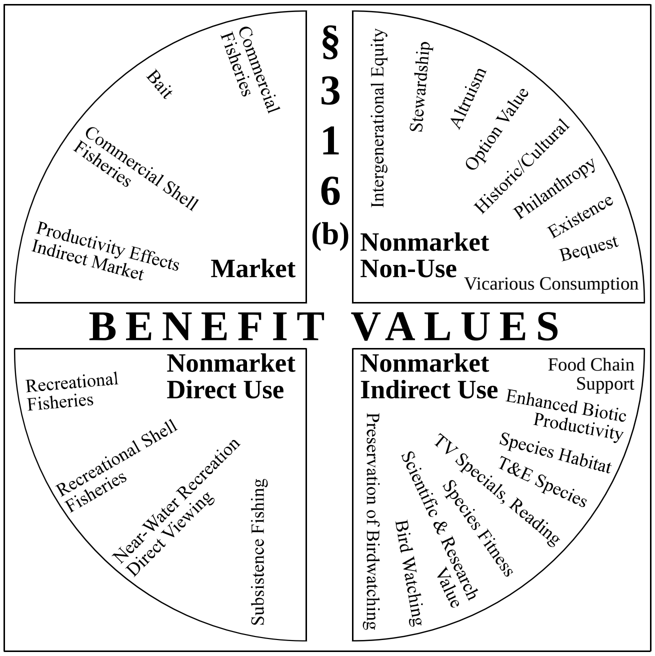
Estimating economic benefits of reducing I&E at existing CWIS can be challenging. Many steps are needed to analyze the link between reductions in I&E and improvements in human welfare. The changes produced by the new regulations on fisheries and other aspects of relevant aquatic ecosystems must be determined, and then linked in a meaningful way to the associated environmental goods and services that ultimately produce increased benefits. Key challenges in environmental benefits assessment include uncertainties, data availability, and the fact that many of the goods and services beneficially affected by CWIS are not traded in the marketplace (i.e., monetary values can not be established based on observed market transactions for some of the important beneficial outcomes). In this case, several types of benefits need to be estimated using nonmarket valuation techniques. Where this cannot be done in a reliable manner, the benefits must be described and considered qualitatively.

---

[1] Technically, consumer surplus reflects the difference between the “value” an individual places on a good or service (as reflected by the individual’s “willingness-to-pay” (WTP) for that unit of the good or service) and the “cost” incurred by that individual to acquire it (as reflected by the “price” of a commodity or service, if it is provided in the marketplace). See Chapter A4 for a more detailed discussion of consumer and producer surplus.

For the regulatory analysis options for Phase III facilities, the benefits are likely to consist of several categories; some are linked to direct use of market goods and services, and others pertain to nonmarket goods and services. Figure A3-1 outlines the most prominent categories of benefits that could be expected from the rule.

Figure A3-1: Benefits Categories for the Section 316(b) Rule for Phase III Facilities



Source: U.S. EPA analysis for this report.

The best example of market benefits for the regulatory analysis options are commercial fisheries, where a change in fishery conditions will manifest itself in the price, quantity, and/or quality of fish harvests. These fishery changes result in changes in the marketplace, and can be evaluated based on market exchanges. A discussion of methods used in the commercial fishing benefits analysis can be found in Chapter A4 of this document.

Direct use benefits also include the value of improved environmental goods and services used and valued by people (whether or not these services and goods are traded in markets). A typical nonmarket direct use would be recreational angling. Recreational fishing studies of sites throughout the United States have shown that anglers place high value on their fishing trips and that catch rates are one of the most important attributes contributing to the quality and, as a result, value of their trips. Higher catch rates resulting from reduced I&E of fish species targeted by recreational anglers may translate into two components of recreational angling benefits: (1) an increase in the value of existing recreational fishing trips resulting in a more enjoyable angling experience, and (2) an increase in recreational angling participation. A discussion of methods used to value recreational fishing benefits can be found in Chapter A5.

Indirect use benefits refer to changes that contribute indirectly to an increase in welfare for users of the resource. An example of an indirect benefit would be when the increase in the number of forage fish enables the population of valued predator species to improve (e.g., when the size and numbers of prized recreational or commercial fish increase because their food source has been improved). In such a context, reducing I&E of forage species will indirectly result in welfare gains for recreational or commercial anglers. See Chapter A1 for a discussion on the indirect influence of forage fish on abundance of commercial and recreational species.

Non-use benefits, often referred to as passive use benefits, arise when individuals value improved environmental quality apart from any past, present, or anticipated future use of the resource in question. Such passive use values have been categorized in several ways in the economic literature, typically embracing the concepts of existence, altruism, and bequest motives. Existence value is the value that individuals may hold for simply knowing that a particular good exists regardless of its present or expected use.[2] This motive applies not only to protecting endangered and threatened species (i.e., avoiding an irreversible impact), but also applies (though perhaps the values held may be different) for impacts that potentially are reversible or that affect relatively abundant species and/or habitats. Bequest value occurs when someone gains utility through knowing that an amenity will be available for others (family or future generations) now and in the future (Fisher and Raucher, 1984). Altruistic values arise from interpersonal concerns (valuing the happiness that others get from enjoying the resource). Non-use values also may include the concept that some ecological services are valuable apart from any human uses or motives. Examples of these ecological services may include improved reproductive success for aquatic and terrestrial wildlife, increased diversity of aquatic and terrestrial species, and improved conditions for recovery of I&E species.

In older published studies, option value, which may exist regardless of actual future use, has been classified as either non-use value, use value, or as a third type of value, apart from both the use and non-use components of total value.[3] Fisher and Raucher (1984) define *option price* for such an individual as "the sum of the expected value of consumer surplus from using the resource plus an *option value* or risk premium that accounts for uncertainty in demand or in supply." Mitchell and Carson (1989) argue that on theoretical grounds this risk premium should be small for non-unique resources. It is increasingly recognized, however, that option value "cannot be a separate component of value" (Freeman, 2003; p. 249). Accordingly, the following analysis does not assess option value as a distinct component of value.

Although different benefit categories can be developed, it makes little difference where specific types of benefits are classified as long as the classification system captures all of the types of beneficial outcomes that are expected to arise from a policy action, while at the same time avoiding any possible double counting. Some valuation approaches may capture more than one benefit category or reflect multiple types of benefits that exist in more than one category or quadrant in the diagram. For example, reducing I&E may enhance populations of recreational, commercial, and forage species alike. Thus, decision-makers need to be careful to account for the mix of direct and indirect uses included in the benefits estimates, including both market and nonmarket goods and services as well as non-use values.

---

[2] The term "existence value" is sometimes used interchangeably with or in place of "non-use value." In this case, where the whole of non-use benefits is represented, existence value has been described as including vicarious consumption and stewardship values. Vicarious consumption reflects the value individuals may place on the availability of a good or service for others to consume in the current time period, and stewardship includes inherent value as well as bequest value. In this case inherent value may be considered the existence value individuals hold for knowing that a good exists (described above), and bequest value is the value individuals place on preserving or ensuring the availability of a good or service for family and others in the future.

[3] Some economists consider option values to be a part of non-use values because the option value is not derived from actual current use. Alternatively, some other writers place option value in a use category, because the option value is associated with preserving opportunity for a future use of the resource. Both interpretations are supportable, but for this presentation EPA places option value in the non-use category in Figure A3-1.

A3-2 Direct Use Benefits

Direct use benefits are the simplest to envision. The welfare of commercial, recreational, and subsistence fishers is improved when fish stocks increase and their catch rates rise. This increase in stocks may result from reduced I&E of species sought by fishers, or from reduced I&E of forage and bait fish, which leads to increases in commercial and recreational species that prey on the forage species (see section A3-3, Indirect Use Benefits, for the latter). For subsistence fishers, the increase in fish stocks may reduce the amount of time spent fishing for their meals or increase the number of meals they are able to catch. For recreational anglers, more fish and higher catch rates may increase the enjoyment of a fishing trip and may also increase the number of fishing trips taken. For commercial fishers, larger fish stocks may lead to increased revenues through increases in total landings and/or increases in the catch per unit of effort (i.e., lower costs per fish caught). Increases in catch may also lead to growth in related commercial enterprises, such as commercial fish cleaning/filleting, commercial fish markets, recreational charter fishing, and fishing equipment sales.[4]

There is ample evidence that the use value of fishery resources is considerable. For example, in 2001, over 34 million recreational anglers spent nearly $35.6 billion on equipment and fishing trip related expenditures (U.S. DOI, 2002), and the 1996 GDP from fishing, forestry, and agricultural services (not including farms) was about $39 billion (BEA, 1998). Americans spent an estimated 557 million days engaged in recreational fishing in 2001, an increase of 9% over the 1991 levels (U.S. DOI, 1993, 2002). If the average consumer surplus per angling day were only $20 — a conservative figure relative to the values derived by economic researchers over the years (Walsh et al., 1990)[5] — then the national level of consumer surplus based on these 1996 levels of recreational angling would be approximately $12.6 billion per year (and probably is appreciably higher).

However, these baseline values do not provide a sense of how benefits change with improvements in environmental quality, such as those due to reduced I&E and increased fish stocks. If the improvement resulted in an aggregate increase of 1.0% in recreational angling consumer surplus, it would translate into potential recreational angling benefits of approximately $100 million per year or more, based on the limited metrics in the previous paragraph.

Methodologies for estimating use values for recreational and commercial species are well developed, and some of the species affected by I&E losses have been extensively studied. As a result, estimation of associated use values is often considered to be straightforward.
The following bullets discuss techniques of estimating direct use value for I&E losses of harvested fish.

- **Commercial fisheries**

The social benefits derived from increased landings by commercial fishers can be valued by examining the markets through which the landed fish are sold. The first step of the analysis involves a fishery-based assessment of I&E-related changes in commercial landings (pounds of commercial species as sold dockside by commercial harvesters). The changes in landings are then valued according to market data from relevant fish markets (dollars per pound) to derive an estimate of the change in gross revenues to commercial fishers. The final steps entail converting the I&E-related changes in gross revenues into estimates of social benefits. These social benefits consist of the sum of the producers' and consumers' surpluses that are derived as the changes in commercial

---

[4] Increased revenues are often realized by commercial ventures whose businesses are stimulated by environmental improvements. These revenue increases do not necessarily reflect gains in national level "economic welfare" and, therefore, are not usually included in a national benefit-cost analysis. However, these positive economic impacts may be sizable and of significance to local or regional economies — and also of national importance — in times when the economy is not operating at full capacity (i.e., when the economic impacts reflect real gains and not transfers of activity across regions or sectors).

[5] Walsh et al. (1990) review 20 years of research and derive an average value of over $30 per day for warm water angling, and higher values for cold water and saltwater angling.

landings work their way through the multi-market commercial fishery sector. Each step of this analysis is described in detail in Chapter A4.

❖ Recreational fisheries

The benefits of recreational use cannot be tracked in the market, since much of the recreational activity associated with fisheries occurs as nonmarket events. However, a variety of nonmarket valuation methods exist for estimating use value, including both "revealed" and "stated" preference methods (Freeman, 2003). Where appropriate data are available or may be collected, revealed preference methods may represent a preferred set of methods for estimating use values. These methods use observed behavior to infer users' value for environmental goods and services. Examples of revealed preference methods include travel cost, hedonic pricing, and random utility models. Compared to non-use values, use values are often considered relatively easy to estimate, due to their relationship to observable behavior, the variety of revealed preference methods available, and public familiarity with the recreational services provided by surface waterbodies.

To evaluate recreational benefits of the regulatory analysis options for section 316(b) Phase III facilities, EPA developed a benefit transfer approach based on a meta-analysis of recreational fishing valuation studies. The analysis was designed to measure the various factors that determine willingness-to-pay (WTP) for catching an additional fish per trip. The estimated meta-model allows calculation of the marginal value per fish for different species, based on resource and policy context characteristics.

Benefit transfer is a secondary research method applied when data and other constraints limit the feasibility of doing site-specific primary research. Although primary research methods are generally considered to be superior to benefit transfer methods, benefit transfer is often a second-best (or only) alternative to original studies. Additional details on the benefit transfer method EPA used in the recreational fishing benefits analysis can be found in Chapter A5, "Recreational Fishing Benefits Methodology."

To validate the meta-analysis results, EPA also used regional random utility models (RUM) of recreational fishing behavior developed for the Phase II analysis to estimate welfare gain to recreational anglers from improved recreational opportunities resulting from reduced I&E of fish species. The models' main assumption is that anglers will get greater satisfaction, and thus greater economic value, from sites where the catch rate is higher due to reduced I&E, all else being equal. This method has been applied frequently to value recreational fisheries and is thought to be quite reliable because it is based on people's demand for nonmarket goods and services through observable behavior. The RUM approach has been applied to the four coastal regions and the Great Lakes region, but was unavailable for the Inland region because of the lack of data on Inland site characteristics, including baseline catch rates and presence of boat ramps and other recreational amenities. Chapter A11 of the Phase II Regional Analysis document provides more detailed discussion of the methodology used in EPA's RUM analysis (U.S. EPA, 2004e).

Results of the RUM models and comparison of the RUM results with the meta-analysis results are presented in Chapters B4 through H4 of the Regional Analysis Document for the proposed section 316(b) regulation for Phase III facilities (U.S. EPA, 2004f). In general, the RUM-based results fall within the range of values estimated based on the meta-model. The fact that the values from the two independent analyses are relatively close supports the use of meta-analysis in estimating the value of resource changes in the context of today's final action.
For the regulatory analysis options considered for the final section 316(b) regulation for Phase existing III facilities, EPA relied only on benefit transfer based on a meta-analysis of recreational fishing valuation studies, as described in Chapter A5. The Agency deemed the use of the proposal RUM models (see EPA-821-R-01-017) in the analysis of the final rule unnecessary for the following reasons: (1) the RUM-based results fall within the range of values estimated based on the meta-model; (2) the use of RUM models is more resource intensive since it requires additional analytic steps; and (3) no RUM models were available for the Inland region.

- **Avoiding double-counting of direct use benefits**

Many of the fish species affected by I&E at CWIS sites are harvested both recreationally and commercially. To avoid double-counting the economic impacts of I&E of these species, the Agency determined the proportions of total species landings attributable to recreational and commercial fishing, and applied these proportions to the total number of affected fish.

- **Subsistence anglers**

Subsistence use of fishery resources can be an important issue in areas where socioeconomic conditions (e.g., the number of low income households) or the mix of ethnic backgrounds make such angling economically or culturally important to a component of the community. In cases of Native American use of affected fisheries, the value of an improvement can sometimes be inferred from settlements in legal cases (e.g., compensation agreements between affected Tribes and various government or other institutions in cases of resource acquisitions or resource use restrictions). For more general populations, the value of improved subsistence fisheries may be estimated from the costs saved in acquiring alternative food sources (assuming the meals are replaced rather than foregone). This method may underestimate the value of a subsistence-fishery meal to the extent that the store-bought foods may be less preferred by some individuals than consuming a fresh-caught fish. Subsistence fishery benefits are not included in EPA's regional analyses. Impacts on subsistence anglers may constitute an important environmental justice consideration, leading to underestimation of the total benefits of the regulatory analysis options.

A3-3 Indirect Use Benefits

Indirect use benefits refer to welfare improvements that arise for those individuals whose activities are enhanced as an indirect consequence of fishery or habitat improvements generated by the regulatory analysis options for Phase III existing facilities. For example, the options' positive impacts on local fisheries may generate an improvement in the population levels and/or diversity of fish-eating bird species. In turn, avid bird watchers might obtain greater enjoyment from their outings, as they are more likely to see a wider mix or greater numbers of birds. The increased welfare of the bird watchers is thus an indirect consequence of the regulatory analysis options' initial impact on fish.

Another example of potential indirect benefits concerns forage species. An improvement in the population of a forage fish species may not be of any direct consequence to recreational or commercial anglers. However, the increased presence of forage fish will have an indirect affect on commercial and recreational fishing values if it increases food supplies for commercial and recreational predatory species. Thus, direct improvements in forage species populations can result in a greater number (and/or greater individual size) of those fish that are targeted by recreational or commercial anglers. In such an instance, the incremental increase in recreational and commercial fishery benefits would be an indirect consequence of the regulatory analysis options' effect on forage fish populations.

A3-4 Non-Use Benefits

In contrast to direct use values, non-use values are often considered more difficult to estimate. Stated preference methods, or benefit transfer based on stated preference studies, are the generally accepted techniques for estimating these values (U.S. EPA, 2000a; U.S. OMB, 2003). Stated preference methods rely on carefully designed surveys, which either (1) ask people about their WTP for particular ecological improvements, such as increased protection of aquatic species or habitats with particular attributes, or (2) ask people to choose between competing hypothetical "packages" of ecological improvements and household cost. In either case, values are estimated by statistical analysis of survey responses.

Non-use values may be more difficult to assess than use values for several reasons. First, non-use values are not associated with easily observable behavior. Second, non-use values may be held by both users and non-users of a resource. Because non-users may be less familiar with particular services provided by a resource, their values may be different from the non-use values for users of the same resource. Third, the development of a defensible stated preference survey is often a time and resource intensive process. Fourth, even carefully designed surveys may be subject to certain biases associated with the hypothetical nature of survey responses (Mitchell and Carson, 1989). Finally, efforts to disaggregate total WTP into its use and non-use components have proved troublesome (Carson et al., 1999).

EPA routinely estimates changes in use values of affected resources as part of regulatory development. However, given EPA's regulatory schedule, developing and implementing stated preference surveys to elicit total value (i.e., non-use and use) of environmental quality changes resulting from environmental regulations is often not feasible. An extensive body of environmental economics literature demonstrates the importance of valuing all service losses, rather than just readily measured direct use losses. These studies typically reveal that the public holds significant value for service flows from natural resources well beyond those associated with direct uses (Fisher and Raucher, 1984; Brown, 1993; Boyd et al., 2001; Fischman, 2001; Heal et al., 2001; Herman et al., 2001; Ruhl and Gregg, 2001; Salzman et al., 2001; Wainger et al., 2001).

Studies have documented public values for the non-use services provided by a variety of natural resources potentially affected by environmental impacts, including fish and wildlife (Stevens et al., 1991; Loomis et al., 2000); wetlands (Woodward and Wui, 2001); wilderness (Walsh et al., 1984); critical habitat for threatened and endangered (T&E) species (Whitehead and Blomquist, 1991; Hagen et al., 1992; Loomis and Ekstrand, 1997); overuse of groundwater (Feinerman and Knapp, 1983); hurricane impacts on wetlands (Farber, 1987); global climate change on forests (Layton and Brown, 1998); bacterial impacts on coastal ponds (Kaoru, 1993); oil impacts on surface water (Cohen, 1986); toxic substance impacts on wetlands (Hanemann et al., 1991); shoreline quality (Grigalunas et al., 1988); and beaches, shorebirds, and marine mammals (Rowe et al., 1992).
Reducing I&E losses of fish and shellfish may result in both use and non-use benefits. Of the organisms that are anticipated to be protected by the regulatory analysis options for the section 316(b) regulation for Phase III facilities, approximately 2.6% will eventually be harvested by commercial and recreational fishers and therefore can be valued with direct use valuation techniques. Unharvested fish, which have no direct use value, represent 97.4% of the total loss. These unlanded fish include forage fish and the unlanded portion of the stock of harvested species. Because unlanded fish contribute to the yield of harvested fish, they have an indirect use value that is captured by the direct use value of the fish that are caught. However, this indirect use value represents only a portion of the total value of unlanded fish. Society may value both landed and unlanded fish for reasons unrelated to their use value. Such non-use values include the value that people may hold simply for knowing these fish exist. EPA believes it is important to consider non-use values. See memorandum entitled "Development of Willingness to Pay Survey Instrument for Section 316(b) Phase III Cooling Water Intake Structures" (Abt Associates, 2006) for more information on efforts to quantify non-use values.

To assess public policy significance or importance of the ecological gains from the regulatory analysis options for Phase III facilities, EPA considered non-use benefits of the options qualitatively. Chapter A6 provides a qualitative assessment of non-use benefits stemming from the regulatory analysis options. Approaches to valuing I&E impacts on special status species are examined in Chapter A9.

A3-4.1 Role of Non-Use Benefits in the Benefits Analysis for the Regulatory Analysis Options for Phase III Facilities

Accounting for non-use values in the Phase III benefits analysis is important because the portion of I&E losses consisting of organisms that may be valued through measuring direct human use value () represent only portion of the organisms impinged and entrained by CWIS. Unlanded fish include forage fish and the unlanded portion of the stock of harvested species. The value to the public of unlanded fish has two sources: (1) their indirect use as both food and breeding population for fish that are harvested; and (2) their non-use value, the value that people may hold simply for knowing these fish exist, stemming from a sense of altruism, stewardship, bequest, or vicarious consumption, as indicated by the willingness of individuals to pay for protecting these fish or increasing their numbers. The indirect use value of forage fish is estimated by translating foregone production among forage species into foregone production among harvested fish.[6] While non-use values are difficult to quantify, EPA believes it is important to consider such values, particularly since 97.4% of impinged and entrained organisms have no direct use value.

As EPA attempted, but was unable, to monetize the non-use benefits associated with unlanded fish, EPA has ascribed these non-use benefits qualitatively. Table A3-1 provides detailed information on the number and percentage of organisms and age-1 adult equivalent losses valued by EPA in the commercial and recreational fishing benefits analyses. As shown in the table, the percent of impinged and entrained organisms that have no direct use value is approximately 97% under the baseline conditions. The organisms that remain unvalued in the analysis provide many important ecological services that do not translate into direct human use. While some ecological services of aquatic species have been studied, other ecosystems services, relationships, and interrelationships are unknown or poorly understood. To the extent that the latter are not captured in the benefits analyses, total benefits are underestimated.

All individuals, including both commercial and recreational fishers as well as those who do not use the resource, may have non-zero non-use values for unlanded and forage fish.

Table A3-1: Number and Percentage of Baseline I&E Losses by Species Category

	Age-1 Adult Equivalents (millions)					
			Commercial and Recreational Species		Harvested Commercial and Recreational Species	
Region	**All Species**	**Forage Species**	**I&E**	**Percentage of Total I&E**	**I&E**	**Percentage of Total I&E**
California	1.71	1.08	0.63	36.84%	0.09	5.38%
North Atlantic	2.31	2.02	0.29	12.55%	0.03	1.21%
Mid-Atlantic	86.42	80.15	6.27	7.26%	1.05	1.22%
South Atlantic	42.12	36.89	5.22	12.39%	0.98	2.32%
Gulf of Mexico	35.77	10.09	25.68	71.79%	3.76	10.51%
Great Lakes	31.54	29.35	2.19	6.94%	0.43	1.35%
Inland	65.11	54.01	11.11	17.06%	0.66	1.01%
National total	264.99	213.58	51.4	19.40%	6.99	2.64%

Source: U.S. EPA analysis for this report.

A3-5 Summary of Benefit Categories

Table A3-2 displays the benefit categories expected to be affected by the regulatory analysis options considered for the final section 316(b) rule for Phase III existing facilities. The table also reveals the various data needs, data sources, and estimation approaches associated with each category. Economic benefits can be broadly defined according to direct use and indirect use, and are further categorized according to whether or not they are traded in the market. As indicated in Table A3-2, “direct use” and “indirect use” benefits include both “marketed” and “nonmarketed” goods, whereas “non-use” benefits include only “nonmarketed” goods.

---

[6] See Chapter A1 of this report for details on this analysis.

Table A3-2: Summary of Benefit Categories
Data Needs, Potential Data Sources, Approaches, and Analyses Completed

Benefit Category	Basic Data Needs	Potential Data Sources/Approaches/Analyses Completed
Direct Use, Marketed Goods		
Increased commercial landings	▸ Estimated change in landings of specific species ▸ Estimated change in total economic impact	▸ Based on facility-specific I&E data and ecological modeling. ▸ Market-based approach using data on landings and the value of landings data from the National Marine Fisheries Service (NMFS).
Fishing tournaments with entry fees and prizes	▸ Estimated change in total economic impact	▸ Not estimated. Changes in tournament participation are expected to be negligible because fishery yield impacts are generally small.
Indirect Use, Market Goods		
Increase in market values: ▸ equipment sales, rental, and repair ▸ bait and tackle sales ▸ increased consumer market choices ▸ increased choices in restaurant meals ▸ increased property values near the water ▸ ecotourism (charter trips, festivals, other organized activities with fees such as riverwalks)	▸ Estimated change in landings of specific species ▸ Relationship between increased fish/shellfish landings and secondary markets ▸ Local activities and participation fees ▸ Estimated numbers of participating individuals	▸ Not estimated due to data constraints such as information on relationship between increase fish/shellfish yield and secondary impacts.
Direct Use, Nonmarket Goods		
Improved value of a recreational fishing trip: ▸ increased catch of targeted/preferred species ▸ increased incidental catch	▸ Estimated number of affected anglers ▸ Value of an improvement in catch rate	▸ Benefit transfer. ▸ Regional RUM analysis (to validate benefit transfer).
Increase in recreational fishing participation	▸ Estimated number of affected anglers or estimate of potential anglers ▸ Value of an angling day	▸ Not estimated. Changes in recreational participation are expected to be negligible at the regional level because fishery yield impacts are generally small.

Table A3-2: Summary of Benefit Categories
Data Needs, Potential Data Sources, Approaches, and Analyses Completed

Benefit Category	Basic Data Needs	Potential Data Sources/Approaches/Analyses Completed
Indirect Use, Nonmarket Goods		
Increase in value of boating, scuba-diving, and near-water recreational experience: ▸ enjoying observing fish while boating, scuba-diving, hiking, or picnicking ▸ watching aquatic birds fish or catch aquatic invertebrates	▸ Estimated number of affected near-water recreationists, divers, and boaters ▸ Value of boating, scuba-diving, and near-water recreation experience	▸ Not estimated due to data constraints such as number of affected recreational users.
Increase in boating, scuba-diving, and near-water recreation participation	▸ Estimated number of affected boating, scuba-diving, and near-water recreationists ▸ Value of a recreation day	▸ Not estimated. Changes in recreational participation are expected to be negligible at the regional level because fishery yield impacts are generally small.
Non-use, Nonmarket Goods		
Increase in non-use values: ▸ existence (stewardship) ▸ altruism (interpersonal concerns) ▸ bequest (interpersonal and intergenerational equity) motives ▸ appreciation of the importance of ecological services apart from human uses or motives (e.g., eco-services interrelationships, reproductive success, diversity, and improved conditions for recovery)	▸ I&E loss estimates ▸ Primary research using stated preference approach ▸ Applicable studies upon which to conduct benefit transfer	▸ Site-specific studies or national stated preference surveys. ▸ Benefit transfer of values for preserving T&E species.

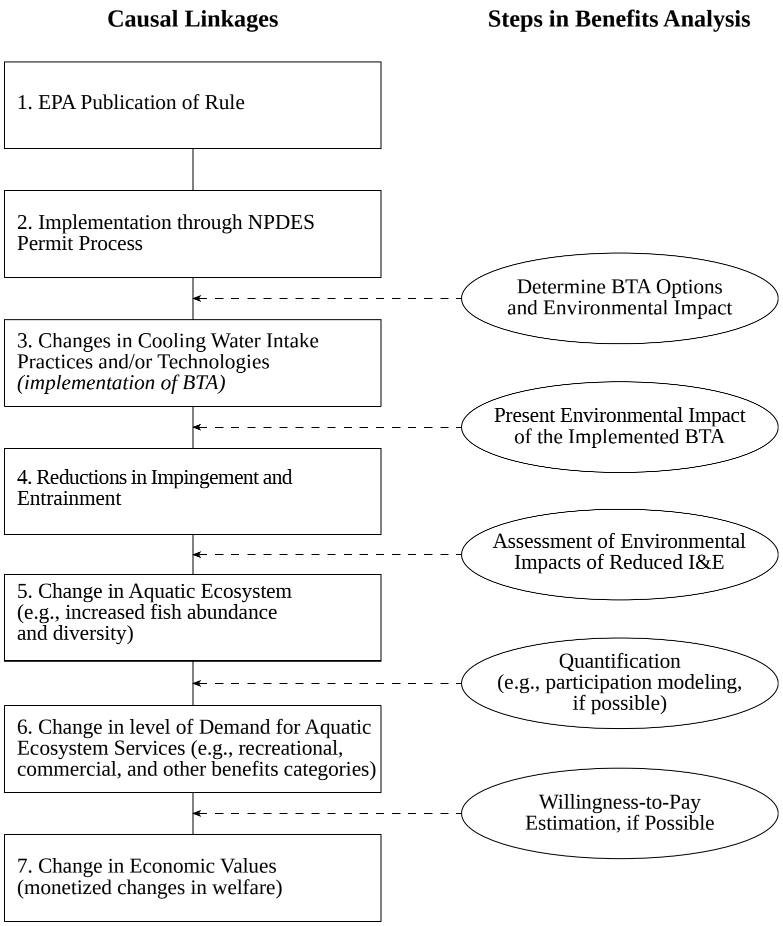
Source: U.S. EPA analysis for this report.

A3-6 Causality: Linking the Regulatory Analysis Options for Phase III Existing Facilities to Beneficial Outcomes

Understanding the anticipated economic benefits arising from changes in I&E requires understanding a series of physical and socioeconomic relationships linking the installation of the Best Technology Available (BTA) to changes in human behavior and values. As shown in Figure A3-2, these relationships span a broad spectrum, including institutional relationships that define rule requirements (from policy making to field implementation), the technical performance of BTA, the population dynamics of affected aquatic ecosystems, and the human responses and values associated with these changes.

The first two steps shown in Figure A3-2 reflect the institutional aspects of implementing the section 316(b) rule for Phase III facilities. In step 3, the anticipated applications of BTA (or a range of BTA options) is determined for the regulated entities. This technology provides the basis for estimating the cost of compliance and the initial physical impacts of the rule (step 4). Hence, the analysis must predict how implementation of BTAs (as predicted in step 3) translates into changes in I&E at a regulated CWIS (step 4). These changes in I&E then serve as inputs for the ecosystem modeling (step 5).

Figure A3-2: Causal Linkages in the Benefits Analysis



Source: U.S. EPA analysis for this report.

In moving from step 4 to step 5, the ecosystem models are used to assess the changes in the aquatic ecosystem from the pre-regulatory baseline (e.g., losses of aquatic organisms before rule implementation) to the post-regulatory conditions (e.g., losses after rule implementation). The potential output from these steps includes estimates of reductions in I&E rates, and changes in the abundance and diversity of aquatic organisms of commercial, recreational, ecological, or cultural value, including T&E species.

In step 6, the analysis involves estimating how the changes in the aquatic ecosystem (estimated in step 5) translate into changes in the level of demand for goods and services. For example, the analysis needs to establish links between improved fishery abundance, potential increases in catch rates, and enhanced participation. Then, in step 7, economic values(for example, the value of the increased enjoyment realized by recreational anglers) are estimated. These last two steps are the focal points of the economic benefits portion of the analysis.

A3-7 Conclusions

The general methods described here are applied in the regional studies, which are reported in Parts B through H of this document. The regional analyses may apply variations of these general methodologies to better reflect site-specific circumstances or data availability.

Chapter A4: Methods for Estimating Commercial Fishing Benefits

Introduction

Commercial fisheries can be adversely impacted by impingement and entrainment (I&E) and many other stressors. Because commercially landed fish are exchanged in markets with observable prices and quantities, estimating the economic value of losses due to I&E (or the economic value of the benefits of reducing I&E) may appear relatively straightforward. However, many complicating conceptual and empirical issues pose significant challenges to estimating the change in economic surplus from changes in the number of commercially targeted fish.

This chapter provides an overview of these issues, and indicates how EPA estimated the change in commercial fisheries-related economic surplus associated with the regulatory analysis options for the section 316(b) regulation. The chapter includes a review of the concept of economic surplus, and describes economic theory and empirical evidence regarding the relationship between readily observable dockside prices and quantities and the economic welfare measures of producer and consumer surplus that are suitable for a benefit-cost assessment.

This chapter also provides an overview of the commercial fishery sector, including an assessment of several relevant fishery stocks and their management, trends and patterns in the commercial fishing industry, and issues of commercial fisheries management and how they affect the analysis of economic welfare measures.

A4-1 Overview of the Commercial Fisheries Sector

Decreased I&E is expected to increase the number of fish available for harvest. The market and welfare impacts of a change in commercial fishery harvests can be traced through a series of economic agents — individuals and businesses — linked through a series of “tiered markets.”

Chapter Contents

A4-1 Overview of the Commercial Fisheries Sector A4-1
  A4-1.1 Commercial Fishers A4-2
  A4-1.2 Processors, Wholesalers, and Other Middlemen A4-2
  A4-1.3 Final Consumers A4-2
A4-2 The Role of Fishing Regulations and Regulatory Participants A4-2
A4-3 Overview of U.S. Commercial Fisheries A4-4
A4-4 Prices, Quantities, Gross Revenue, and Economic Surplus A4-5
  A4-4.1 Accuracy of Price and Quantity Data A4-5
  A4-4.2 The Impact of Potential Price Effects A4-6
  A4-4.3 Key Concepts Applicable to the Analysis of Revenues and Surplus A4-7
  A4-4.4 Estimating Changes in Price (as applicable) A4-9
A4-5 Economic Surplus A4-10
  A4-5.1 Consumer Surplus A4-10
  A4-5.2 Producer Surplus A4-11
A4-6 Surplus Estimation When There is No Anticipated Change in Price A4-12
  A4-6.1 Producer Surplus as a Percentage of Gross Revenues: Assuming No Change in Prices A4-13
  A4-6.2 Unregulated Fisheries A4-13
  A4-6.3 Regulated Fisheries A4-13
  A4-6.4 Conclusions on Surplus When No Change in Price is Anticipated A4-14
A4-7 Surplus Estimation Under Scenarios in Which Price May Change A4-14
  A4-7.1 Neoclassical Economic Perspective on the Market and Economic Welfare A4-15
  A4-7.2 Issues in Estimating Changes in Welfare A4-15
A4-8 Estimating Post-Harvest Economic Surplus in Tiered Markets A4-17
A4-9 Nonmonetary Benefits of Commercial Fishing. A4-18
A4-10 Estimating Producer Surplus A4-19
  A4-10.1 Introduction A4-19
  A4-10.2 Methodology A4-19
  A4-10.3 Region-Specific Estimates of Net Benefits Ratios A4-21
A4-11 Methods Used to Estimate Commercial Fishery Benefits from Reduced I&E; Summary A4-27
A4-12 Limitations and Uncertainties A4-28

Commercial fishers, the individuals engaged in harvesting fish, typically haul their catch to established dockside wholesale markets, where they sell their catch to processors or wholesalers. Processors package or can the fish, then sell them as food products for people, as pet and animal feed, or as oils and meals for various other uses. Wholesalers often resell fish to retailers (e.g., grocery stores), restaurants, or final consumers (households).

Through these economic relationships between various levels of buyers and sellers, the final value of the fish or fish product creates economic signals (e.g., prices) that return through the various intermediate parties to the fishers. Additionally, beneficial changes in the commercial fishery may encourage fishers to purchase more variable inputs such as fishing gear, fuel, and vessel repairs as well as fixed inputs such as fishing boats. Additional expenditures would benefit the suppliers of these goods and services. However, such purchases from input suppliers would not typically be estimated as part of benefits, because they are transfers and transfers are excluded because they have zero net effect to society as a whole.

A4-1.1 Commercial Fishers

Commercial fishers include the individuals supplying the labor and/or capital (e.g., fishing vessels) to harvesting fish. These fishers typically haul their catch to established dockside wholesale markets, where they sell their catch to processors or wholesalers. The transactions between the fishers and these intermediate buyers provide observable market quantities and prices of dockside landings, and it is these data that serve as a starting point for estimating changes in economic surplus.

Commercial fishing is often a demanding and risky occupation. However, commercial anglers often find great satisfaction in their jobs and lifestyles. Additional details on the economic and non-economic aspects of commercial fishing are provided in several of the sections that follow, including a discussion of the non-monetary benefits of commercial fishing.

A4-1.2 Processors, Wholesalers, and Other Middlemen

Dockside transactions typically involve buyers for whom the fish are an input to their production or economic activity. For example, processors convert raw fish into various types of final or intermediate products, which they then sell to other entities (e.g., retailers of canned or frozen fish products, or commercial or industrial entities that rely on fish oil as a production input). Wholesalers may serve as middlemen between the fishers and retail vendors (e.g., supermarkets) or those who use fish as production inputs. Depending on the market and the type of fish, there may be numerous intermediaries between the commercial fishers and the final consumers who eat or otherwise use the fish or fish products.

A4-1.3 Final Consumers

After passing through perhaps several intermediate buyers and sellers, the fish (or fish products) ultimately end up with a final consumer (typically a household). This final consumption may take the form of a fish dinner prepared at home or purchased in a restaurant. Final consumption may also be in the form of food products served to household pets, or as part of a nonfood product that relies on fish parts or oils as an input to production.

A4-2 The Role of Fishing Regulations and Regulatory Participants

Transactions in the fishery sector are often affected by various levels of fishery management regulations. Nearshore fishing (ocean and estuary fishing less than 3 miles from shore) and Great Lakes fishing are primarily regulated by State, Interstate, and Tribal entities. The content and relative stringency of State laws affecting ocean fishing vary from state to state.

The regulated nature of many fisheries affects the manner in which the impacts and economic benefits of the regulatory analysis options for the section 316(b) regulation should be evaluated. For example, if the affected fisheries were perfectly competitive with open access (i.e., no property rights or fishery regulations), then all economic rents, surplus, and profits associated with the resource would be driven to zero at the margin. However, where fisheries are regulated or in other ways depart from the neoclassical assumptions of perfectly competitive markets, there are rents and surplus that will be affected by changes in I&E. These economic considerations are addressed later in this chapter.

The primary Federal laws affecting commercial fishing in U.S. ocean territory are the Magnuson Fishery Conservation and Management Act of 1976 and the Sustainable Fisheries Act (SFA) of 1996 (the SFA amended the 1976 act and renamed it the Magnuson-Stevens Fishery Conservation and Management Act). The purpose of the 1976 act was to establish a U.S. exclusive economic zone that ranges from 3 to 200 miles offshore, and to create eight regional fishery councils to manage the living marine resources within that area. These councils comprise “commercial and recreational fishers, marine scientists and State and Federal fisheries managers, who combine their knowledge to prepare Fishery Management Plans (FMPs) for stocks of finfish, shellfish and crustaceans. In developing these FMPs the Councils use the most recent scientific assessments of the ecosystems involved with special consideration of the requirements of marine mammals, sea turtles and other protected resources” (NMFS, 2002c). The SFA amended the law to include numerous provisions requiring science, management, and conservation actions by the National Marine Fisheries Service (NMFS) (NMFS, 2002e).

The eight fishery management councils created by the 1976 act have regulatory authority within the eight regions. They receive technical and scientific support from the National Oceanic and Atmospheric Administration (NOAA), NMFS Fisheries Science Centers, which are organized into the following regions: Alaska, Northeast, Northwest, Southeast, and Southwest. Table A4-1 presents how the regions used for this analysis fit into the fishery management council regions and other fishery regions defined by NMFS.

Table A4-1: Regional Designation of Fisheries

EPA 316(b) Analysis Region	States	NMFS Science	NMFS Marine Recreation Region	NMFS Commercial Region	Fishery Management Council (FMC)	Large Regions Reported in *Our Living Oceans* (NMFS, 1999a)
North Atlantic	Maine, New Hampshire, Massachusetts, Connecticut, Rhode Island	Northeast	North Atlantic	New England	New England	Northeast
Mid-Atlantic	New York, New Jersey, Delaware, Maryland, District of Columbia, Virginia	Northeast	Mid-Atlantic	Chesapeake Mid-Atlantic	Mid-Atlantic	Northeast
South Atlantic	North Carolina, South Carolina, Georgia, Florida (Atlantic Coast)	Southeast	South Atlantic	South Atlantic	South Atlantic	Southeast
Gulf of Mexico	Florida (Gulf Coast), Alabama, Mississippi, Louisiana, Texas	Southeast	Gulf of Mexico	Gulf	Gulf of Mexico	Southeast
Northern California	California, north of San Luis Obispo/Santa Barbara county border	Southwest	Northern California	Pacific Coast	Pacific Coast	Pacific Coast
Southern California	California, south of San Luis Obispo/Santa Barbara county border	Southwest	Southern California	California	Pacific Coast	Pacific Coast
Great Lakes	Minnesota, Wisconsin, Illinois, Indiana, Michigan, Ohio, Pennsylvania, New York	Northeast	NA	Great Lakes	NA	NA

A4-3 Overview of U.S. Commercial Fisheries

In estimating the benefits of reducing I&E losses, it is important to understand how increased fish populations may affect stocks in different fisheries. Where stocks are thriving, a small increase in the number of individual fish affected by I&E may not be noticed, but where stocks are already depleted the marginal impact of a small increase may be much more important.

Many fisheries in the United States tend to be heavily fished. In the mid-1900s, many U.S. fisheries were over-fished, some to the point of near collapse (NMFS, 1999b, 2001a; U.S. Bureau of Labor Statistics, 2002). The situation currently is showing some gradual improvement because of recent management efforts mandated by the Magnuson-Stevens Act and other regulations. However, many of the current restrictions on fishing have not been in place long enough to have a dramatic impact on fisheries.

Table A4-2 shows the utilization rate of fisheries in the United States by region, based on data reported in *Our Living Oceans* (NMFS, 1999b). The regions for which fish status are reported in NMFS (1999b), listed in Table A4-2, are larger than those used in the section 316(b) Phase III regional analysis. The NMFS Northeast region includes both the North Atlantic and the Mid-Atlantic regions as defined for EPA's analysis; the NMFS Southeast region includes EPA's South Atlantic and Gulf of Mexico regions; and the NMFS Pacific Coast region includes EPA's Northern California and Southern California regions, as well as Oregon and Washington.

Table A4-2: Utilization of U.S. Ocean and Nearshore Fisheries in 1999

Our Living Ocean Regions[a]	# Fisheries with Known Status	# Fisheries with Unknown Status	# Under-Utilized	# Fully-Utilized	# Over-Utilized
Alaska	43	8	10	33	0
Northeast	55	15	4	15	36
Pacific Coast	55	11	12	37	6
Southeast	34	35	2	15	17
Western Pacific	20	7	8	9	3
Total	207	76	36	109	62
% of Total with Known Status			17%	53%	30%

[a] The Northeast region includes EPA's North Atlantic and Mid-Atlantic regions; the Pacific Coast region includes EPA's Northern and Southern California regions, as well as Oregon and Washington; and the Southeast region includes EPA's South Atlantic and Gulf of Mexico regions. The Alaska and Western Pacific regions are not included in the Phase III CWIS benefit-cost analysis, but are included here for comparison.

Source: NMFS, 1999b.

Based on the NMFS definitions, a fishery is considered to be producing at a less than optimal level if its recent average yield (RAY)[1] is less than the estimated long-term potential yield (LTPY).[2] This can occur as a result of either under-utilization of the fishery or collapse of the fish stock. These data indicate that a majority, 53%, of the

---

[1] RAY is measured as "reported fishery landings averaged for the most recent 3-year period of workable data, usually 1995-1997" (NMFS, 1999b, p. 4).

[2] LTPY is "the maximum long-term average catch that can be achieved from the resource. This term is analogous to the concept of maximum sustainable yield (MSY) in fisheries science" (NMFS, 1999b, p. 5). LTPY may not be the yield that maximizes surplus rents.

ocean and nearshore fisheries with known status, were fully utilized in 1999. Approximately 30% of these fisheries are identified as over-utilized. For more than a third of the fisheries, the status is unknown.

Table A4-3 shows the overall production of U.S. fisheries by region. In total, the annual RAY has been over 12 million metric tons, with Alaska and the Western Pacific providing nearly two-thirds of the catch. Because of under-utilization in some fisheries and over-fishing in others, the total RAY in the United States is only 60% of the estimated LTPY.

Table A4-3: Productivity of U.S. Regional Fisheries in 1999 (million metric tons)

Our Living Ocean Regions[a]	Total Long-Term Potential Yield (LTPY)	Total Current Potential Yield (CPY)		Total Recent Average Yield (RAY)		
		CPY	% of LTPY	RAY	% of LTPY	% of CPY
Alaska	4.47	3.52	78.7%	2.51	56.1%	71.3%
Northeast	1.59	1.35	85.2%	0.89	55.7%	65.4%
Pacific Coast	1.04	0.85	81.9%	0.62	59.7%	72.9%
Southeast	1.50	1.15	76.7%	1.16	76.8%	100.2%
Western Pacific	3.44	3.44	100.1%	2.05	59.6%	59.6%
Total	12.04	10.32	85.7%	7.22	60.0%	70.0%

[a] The Northeast region includes EPA's North Atlantic and Mid-Atlantic regions; the Pacific Coast region includes EPA's Northern and Southern California regions, as well as Oregon and Washington; and the Southeast region includes EPA's South Atlantic and Gulf of Mexico regions. The Alaska and Western Pacific regions are not included in the Phase III CWIS benefit-cost analysis, but are included here for comparison.

Source: NMFS, 1999b.

A4-4 Prices, Quantities, Gross Revenue, and Economic Surplus

Dockside landings and revenues are relatively easy to observe, and readily available from NMFS. These data can be used to develop a rough estimate of the value of increased commercial catch. However, it is not always easy to interpret these data properly in estimating benefits. First, there are empirical issues about whether the data accurately reflect the full market value of the commercial catch. Second, simply applying an average price to a change in catch does not account for a potential price response to the change in catch. Third, even if the price effect is accounted for, change in gross revenue is not necessarily the correct conceptual or empirical basis for estimating benefits from reduced I&E. This section addresses these key issues.

A4-4.1 Accuracy of Price and Quantity Data

The commercial landings data available from NOAA Fisheries are the most comprehensive data available at the national and regional levels and thus EPA used these data in its estimation of commercial fishing benefits. Nevertheless, the data may not fully capture the economic value of the commercial catch in the United States. As with any large-scale data collection effort, there are potential limitations such as database overlap and human error. Additional reasons the data may not fully capture the economic value of the commercial catch are varied and include, but are not limited to, the following:

- Fishers often receive noncash payments for their catch. Crutchfield et al. (1982) noted that "the full amount of the payment to fishers should include the value of boat storage, financing, food, fuel, and other non-price benefits that are often provided to fishers by processors. These are clearly part of the overall "price," but are very difficult to measure, since they are not generally applicable to all fishers equally and are not observed as part of dockside prices.

- Some fishers may sell their catch illegally. There are three main reasons why illegal transactions occur:
  - To circumvent quantity restrictions (quotas) on landings allowed under fishery management rules.
  - To avoid or reduce taxes by having a reported income less than true earnings.
  - To reduce profit sharing, boat owners have been known to negotiate a lower price with the buyer and then recover part of their loss "in secret" so they do not have to share the entire profit with the crew.

- Some species are recorded inaccurately. Seafood dealers fill out the reports for commercial landings and may mislabel a species or not specifically identify the species — for example, entering "rockfish" instead of "blue rockfish." In this example the landings data for blue rockfish would under-estimate total landings, while data for "other rockfish" would be over-estimated (personal communication; D. Sutherland, NMFS, Fisheries Statistics and Economics Division, 11/4/2002).

- Federal law prohibits reporting confidential data that would distinguish individual producers or otherwise cause a competitive disadvantage. These "confidential landings" are entered as "unclassified" data (e.g., finfishes, unc.) and do not distinguish individual species. Although most summarized landings are not confidential, species summary data may under-report actual landings if some of those landings have been confidential and therefore were not reported by individual species (NMFS, 2002b).

- Landings data are combined from nine databases that overlap spatially and temporally, and although they are carefully monitored for double-counting, some overlap may go unnoticed (NMFS, 2002b).

A4-4.2 The Impact of Potential Price Effects

A key issue in this analysis is whether the change in fishery conditions associated with the regulatory analysis options will be sufficiently large to generate price changes in the relevant fishery markets.

If the estimated changes in commercial landings are small relative to the applicable markets, then no price change of consequence is likely. This appears to be the case for all regions and fisheries included in this analysis. In this case, estimating benefits is relatively simple. With no change in price, there is a fairly transparent relationship between the change in revenues and the change in economic surplus measures that are suitable for a benefits assessment (i.e., there is no change in consumer surplus, and the change in producer surplus may be equivalent to a percentage of or even equal to the change in revenues). The change in revenues is straightforward to estimate (i.e., the estimated change in quantity landed times the original price). This method is described further later in this chapter.

If changes in landings are such that a price change is anticipated, then the conceptual and empirical analysis becomes more complicated. As detailed in greater depth later in this chapter, a price change makes it more difficult to estimate changes in gross revenues. In fact, the change in revenues may be either positive or negative, depending on the relative elasticity of demand. Further, a change in price is anticipated to generate changes in both producer and consumer surplus, and numerous complex factors must be considered in assessing these changes in welfare (e.g., some of the gain in consumer surplus will reflect a transfer away from producer surplus, the overall change in producer surplus may be positive or negative, and the relationship between these measures of surplus and the estimated market revenues is much less transparent than in the case where price is reasonably constant).

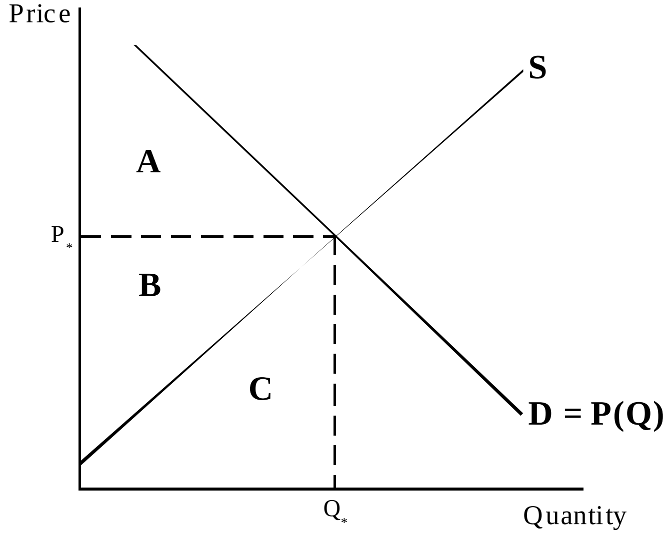
As discussed later in this chapter, in all the regional analyses performed for the final rule the change in estimated harvest is small relative to the applicable market and EPA has assumed that there would be no significant change in price. The issues with estimating changes in revenues and surplus are then relatively straightforward. It may be the case in future rulemakings, however, that price changes are likely to apply in some markets. Therefore, this chapter provides additional discussion of conceptual and empirical issues that may arise when a price change scenario is relevant.

A4-4.3 Key Concepts Applicable to the Analysis of Revenues and Surplus

Before discussing the details of defining and measuring revenues and surplus, it is important to first establish some basic economic concepts relative to markets and measures of welfare. Figure A4-1 depicts a simple market for a typical economic good, with demand (labeled as line D) downward sloping to reflect what economists refer to as decreasing marginal utility, and supply (line S) upward sloping to reflect increasing marginal costs.

There are numerous reasons why the market for commercial fish often differs in important ways from the typical market depicted in the figure. Commercial fisheries are considered renewable natural resources whereby supply is limited by ecological constraints. Fisheries' markets often deviate from the traditional neoclassical view of fully competitive markets because of open access, the socially desirable goal of maximizing resource rents, and the corresponding need for regulations that limit catch or prevent the entry of fishers (suppliers). It is also possible that costs may not increase in the relevant range of changes to fishery conditions. Nonetheless, to introduce some core concepts, we begin with the standard neoclassical depiction of a market as shown in the figure.

Figure A4-1: Market for Typical Economic Good



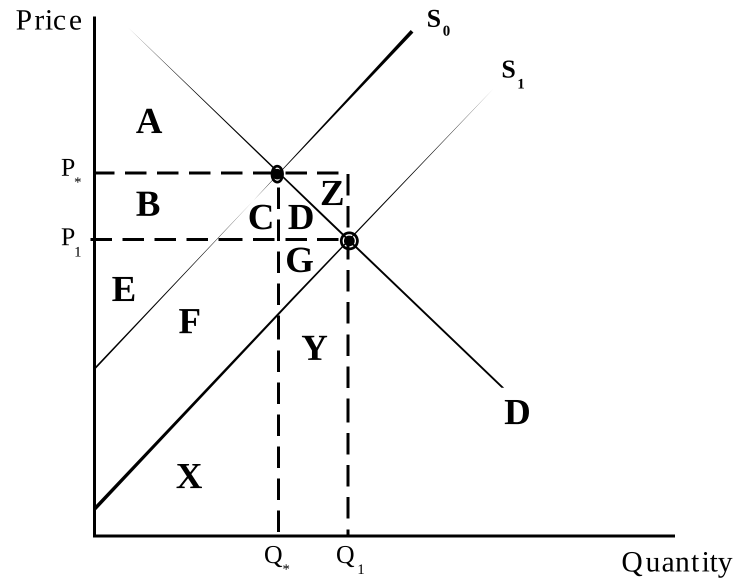
An equilibrium is established where supply and demand intersect, such that Q_* reflects the quantity of the good exchanged and P_* reflects the market clearing price (i.e., the price at which the quantity supplied is equal to the quantity demanded). The gross revenue in this market (the sum total paid by consumers, which is equivalent to payments received by sellers) is equal to P_* multiplied by Q_*, which in the figure is depicted by the rectangle made up of areas B plus C.

While the level of total (gross) revenues is of interest, it does not measure the total benefit (economic welfare) that is generated by this market. This is measured by what is referred to as economic surplus (see sections A4-5.1 and A4-5.2 for further discussion of concepts related to economic surplus). Economic surplus consists of consumer surplus (which is depicted by area A) plus producer surplus (depicted by area B). Consumer surplus is the amount by which willingness-to-pay (WTP), as reflected by the demand curve, exceeds the market-clearing price for each unit exchanged, up to Q_* (i.e., it indicates the degree by which consumers obtained the traded commodity at a price below what the good was worth to them).

Likewise, producer surplus reflects the extent to which suppliers realized revenues above and beyond the marginal cost of producing some of the units (up to Q_*). Beyond Q_*, there is neither additional consumer nor producer surplus to be gained — at the margin, all the surplus has been extracted and no additional surplus will be gained by adding more output to the market.

Now, suppose there is a change that increases the amount of a key input to production, such that the more bountiful input is now available at a lower cost to suppliers than before. For example, an increase in the number of locally harvestable fish makes it easier, and thus less costly, to catch a given number of fish. This could result in an outward shift in supply (a decrease in the marginal cost of producing any given quantity of the good). This is depicted in Figure A4-2, where supply shifts from S_0 to S_1. With the increased supply, a new market clearing price emerges at P_1 (which is lower than the original P_*), and the quantity exchanged increases from Q_* to Q_1.

Figure A4-2: Increased Supply in Typical Economic Market



These changes in the quantity exchanged and the market-clearing price make it somewhat complex to envision how (and by how much) gross revenues and economic surplus measures may change as a consequence of the shift in supply. Using Figure A4-2 as a guide:

- Under the original supply conditions (S_0) consumer surplus had been area A, but it has now increased to A + B + C + D. Therefore, consumer surplus has increased by an amount depicted by areas B + C + D.

- Producer surplus had been area B + E before the supply shift, but becomes E + F + G after the shift in supply. Hence the change in producer surplus is depicted as areas F + G - B.
  - Note that area B is subtracted from producer surplus but added to consumer surplus — i.e., it represents a transfer of surplus from producers to consumers when supply shifts outward and prices decline.
  - Also note that consumer surplus has increased by more than the transfer of area B from producers; the additional consumer surplus (above and beyond the transfer) is depicted by the amount C + D.
  - Finally, note that the change in producer surplus might be positive or negative, depending on whether the addition of F + G outweighs the loss of B (assuming the supply curves are parallel).

- The total change in economic surplus (consumer plus producer surplus) therefore equals C + D + F + G.

- Total revenue had been P_* times Q_* (area B + C + E + F + X), but now becomes P_1 times Q_1 (area E + F + X + G + Y). The change in total revenue thus becomes (G + Y) - (B + C).
  - Note that the change in revenue can be positive or negative, depending on whether G + Y is greater or less than B + C.
  - Also note that if one does not know how much the price will decrease, and relies on the original price (P_*) to estimate the change in revenue, then the change in revenue would be over-estimated as P_* times (Q_1 - Q_*), which is equivalent to the area G + Y + D + Z.
  - If the change in revenue is estimated relying on the original price level (P_*) when in fact the price has changed to P_1, then the amount by which the change in revenue will be over-estimated is equal to area B + C + D + Z.

Even though the illustration above relies on a relatively simple depiction of a market that adheres to the basic economic assumptions and conditions of perfect competition, it reveals how complex the analysis can become if there is an anticipated change in price when supply is increased. The analysis can become even more complex when deviations from the assumptions of open access perfect competition are considered.

A4-4.4 Estimating Changes in Price (as applicable)

One key observation from the illustration above is the importance of predicting the change in price, because relying on the baseline price can lead to potential errors. Correct estimation of the change in price of fish as a result of the regulation requires two pieces of information: the expected change in the commercial catch, and the relationship between demand for fish and the price of fish. Ideally, a demand curve would be estimated for the market for each fish species in each regional market. The level of effort required to model demand in every market is not feasible for this analysis. However, if reasonable, empirically based assumptions can be made for the price elasticity of demand for fish in each region, the change in price can be accurately estimated.

The price elasticity of demand for a good measures the percentage change in demand in response to a percentage change in price. For example, if the price elasticity of demand for fish is assumed to be -2 over the relevant portion of the demand function, then a 1% increase in price creates a 2% *decrease* in the quantity demanded. Essentially, this determines the slope of the demand curve because it indicates how demand responds to a change in price. The inverse of the price elasticity of demand can be used to estimate the change in price as a result of a change in the quantity demanded. If the price elasticity of demand is assumed to be -2, the inverse is 1/-2 = -0.5. This would imply that a 1% increase in demand would correspond to a 0.5% *decrease* in price.

For example, if in Figure A4-2 Q_* is equal to 10,000 pounds of fish per year, and reductions in I&E are expected to add 500 pounds of fish to the annual catch, then Q_1 will equal 10,500 pounds per year. This is a 5% increase in the quantity of fish supplied to the market. Based on the illustration, in response to the increase in supply, price will decrease from P_* to P_1. To clear the market, the quantity demanded would increase until Q_1 is also the quantity of fish demanded. If the price elasticity of demand for fish in this market is known to be approximately -2, then the inverse of the price elasticity of demand is -0.5 and, as described above, the expected change in price necessary to clear the market would be 5% × -0.5 = -2.5%. If the initial price, P_*, equals $1.00 per pound, then P_1 will equal $0.975 per pound, and the change in gross revenues will be (10,500 × $0.975) - (10,000 × $1.00) = $237.50. This represents a 2.375% increase in gross revenues for commercial fishers in this market.

A variety of sources in the economics literature provide estimates of the price elasticity of demand for fish. In this analysis, EPA has assumed that the changes in supply of fish as a result of reduced I&E will not be large enough to create a significant change in price (see discussion below describing regional results). Therefore, assumptions about price elasticity are not necessary in this case. In future analyses, if there are markets in which the estimated change in harvest is predicted to be large enough to generate a price change of consequence, EPA will revisit this issue in light of information available in the literature.

A4-5 Economic Surplus

Even if the change in gross revenue is measured accurately and potential price effects (if any) are accounted for, changes in gross revenues are not generally considered to be a true measure of economic benefits. According to broadly accepted principles of microeconomics, benefits should be expressed in terms of economic surplus to consumers and producers.

A4-5.1 Consumer Surplus

To understand consumer surplus, consider the following illustration. Suppose a seafood lover goes to a fish market and pays $\$P^1$, the current market price, for a pound of salmon. However, she would have been willing to pay more than $\$P^1$ if necessary. The maximum she would have paid for the salmon is $B. The difference between $B and $\$P^1$ represents an additional benefit to the consumer. When this benefit is summed across all consumers in the market, it is called consumer surplus.

Figure A4-3 shows one possible representation of a market for fish. The demand curve, D(F), shows the aggregate demand that would prevail in the market at each price level (P).[3,4] The line Q^1 is the quantity of fish supplied to the market by fishers. Equilibrium is attained a the point where D(F) equals Q^1. Under these conditions, the price is P^1. In this case the total amount paid by consumers for fish is equal to $P^1 \times Q^1$, which is equal to the area of boxes U + V + W in the graph. The extra benefit to consumers, i.e., the consumer surplus, is equal to the area of triangle T.[5]

If the quantity of fish available to the market increases from Q^1 to Q^2, then the price decreases to P^2. This changes the total amount paid by consumers to $P^2 \times Q^2$, which is equal to the area of boxes V + W + Y + Z, and increases the consumer surplus to the area of triangle T + U + X.

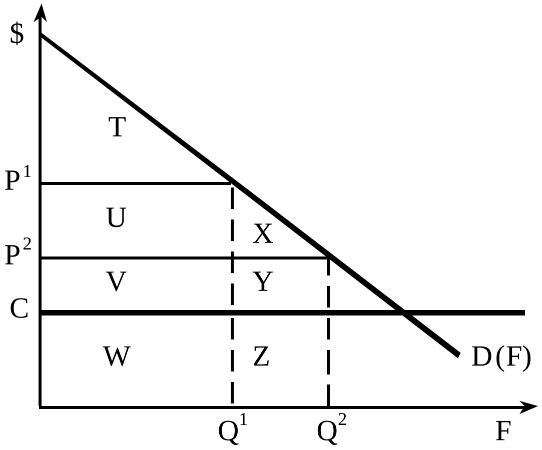
---

[3] Note that in the graph the quantities supplied, Q^1 and Q^2, are assumed to be constant under a given set of conditions. This assumption allows for a simplified case to be presented in the figure. An assumption of constant supply is most appropriate for a short-term analysis or for an analysis of a fishery regulated via quotas. Section A4-6 offers a discussion of the case where the supply curve is upward sloping.

[4] In this simplified illustration D(F) is really an inverse demand curve since it determines price as a function of quantity, F. The distinction is not of vital importance here.

[5] Note that Figure A4-3 is a highly simplified characterization of benefits derived from a commercial fishery, where the goal is to maximize producer surplus and consumer surplus. Figure A4-3 is drawn from Bishop and Holt (2003), who indicate that D(F) represents a general equilibrium demand function, accounting for markets downstream of harvesters, and that the welfare triangle (area T in Figure A4-3) represents consumer surplus plus post-harvest rents. Q^1 is the supply of fish under a fixed, optimal quota before a regulatory analysis option for Phase III facilities and Q^2 is the supply after a regulatory analysis option for Phase III facilities takes effect. A more complete interpretation of the graph in the context of renewable resources also reveals that costs for the harvester (e.g., fishing fleet) are equal to the area W (for a quota equal to Q^1) and that area U + V is equal to the rents potentially captured by the harvester at Q^1.

Figure A4-3: Conceptual Model of Benefits from an Increase in Fish Catch



Source: Bishop and Holt (2003).

A4-5.2 Producer Surplus

In the example above, there is also a producer surplus that accrues to the fish seller. When the fish market sold the salmon to our consumer, it sold it for $P^1 because that was the market price. However, it is likely that it cost less than $P^1 to supply the salmon. If $C is the cost to supply the fish, then the market earns a profit of $P^1 minus $C per fish. This profit is akin to the economic concept of producer surplus.[6]

In Figure A4-3, the line C represents a simplified representation of the cost to the producer of supplying a pound of fish.[7] When the supply of fish is equal to Q^1, the producers sell Q^1 pounds of fish at a price of P^1. The difference between P^1 and C is the producer surplus that accrues to producers for each pound of fish.[8] Total producer surplus realized by producers is equal to $(P^1 - C) \times Q^1$. In the example, this producer surplus is equal to the area of U + V. The area W is the amount that producers pay to their suppliers if the harvest equals Q^1. In the example presented here, W might be the amount that the fish market paid to a fishing boat for the salmon plus the costs of operating the market.

---

[6] Producer surplus equals economic profit minus the opportunity cost of the owner's resources invested in the fishery enterprise (see section A4-8 for additional details).

[7] In this case average cost is assumed to equal marginal cost at C and the marginal cost is assumed constant. Note that this is a simplification used here only to assist with the discussion. For example, the regulatory analysis options for the section 316(b) rulemaking might lead to a small decrease in cost per unit of fish caught. Also, if marginal cost were assumed to be upward sloping, the figure would more closely resemble the familiar graph of supply and demand with an upward-sloping supply curve, as depicted in Figure A4-2.

[8] Note that economists usually assume that C includes the opportunity cost of investing and working in commercial fishing. Thus, producer surplus is profit earned above and beyond normal profit. In a perfectly competitive market, when economic profit is being earned, it induces more producers to join the market until producer surplus is zero. However, many commercial fisheries are no longer allowing open access to all fishers, thus it is realistic to assume that a level of producer surplus greater than zero is attainable in many U.S. commercial fisheries. In the case of managed fisheries, $(P^1 - C)$ can be referred to as rent.

When supply increases to Q^2, the producers sell Q^2 pounds of fish at a price of P^2. The total cost to produce Q^2 increases from W to W + Z. The total producer surplus changes from U + V to V + Y.[9]

In this simple example, where cost, C, is assumed to be constant, the producer surplus earned by suppliers is equal for all units of fish harvested. If C increases as harvest increases, however, some of the producer surplus per unit will be eaten away by increased costs. In the figure, this would be seen as a decrease in the areas of V and Y and an increase in the areas of W and Z as a greater share of the revenues from the sale of the catch go to cover costs.

Figure A4-3 is a graphical representation of a single market. In the real world, a fishing boat captain will sell the boat's catch to a processor, who sells processed fish to fish wholesalers, who in turn sells fish to retailers, who may sell fish directly to a consumer, or to a restaurant that will sell fish to a consumer. There will be consumer and producer surplus in each of these markets.[10] As a result, it is conceptually inaccurate to estimate the change in the quantity of fish harvested, multiply by the price per pound, and call this change in gross revenue the total benefits of the regulation.

The sections of this chapter that follow detail methods used in the analysis of commercial fishing benefits attributable to the regulatory analysis options considered for the final section 316(b) rule for Phase III existing facilities. This involves three basic steps: estimating the increase in pounds of commercial catch under the regulatory analysis options, estimating the gross value of the increased catch, and estimating the increase in producer surplus as a proportion of increased gross value. If the regulatory analysis options were expected to have a greater impact on markets, an additional step would be estimating the increase in consumer surplus across all affected markets as a proportion of increased gross value. However, as detailed above, EPA has assumed that the changes in supply of fish as a result of reduced I&E will not be large enough to create a significant change in price. In addition:

- A considerable proportion of the commercial catch is exported, and thus does not benefit domestic/regional consumers.
- Many of the commercially traded species are traded in highly competitive markets, which include a number of substitute species (both imported and other domestic species) so that prices to consumers are not likely to be significantly affected by the expected marginal increase in domestic catch.

Consequently, EPA assumes consumer surplus to equal zero. Nevertheless, section A4-7 describes potential methods in the case of a price change.

A4-6 Surplus Estimation When There is No Anticipated Change in Price

Overall, the estimated changes in landings due to the regulatory analysis options considered for the final section 316(b) rule for Phase III existing facilities are not expected to greatly influence markets for the fish. Thus, it seems reasonable to presume that there will be no appreciable impacts on wholesale or retail fish prices. Under a scenario where prices are not affected, economic theory indicates that the total change in economic welfare will be confined to changes in producer surplus (i.e., changes in consumer and related post-harvest surplus will be zero). Benefits estimation will therefore consist of measuring producer surplus, and the core empirical and conceptual issue

---

[9] Note that the producer surplus may be smaller at quantity Q^2 than at Q^1, depending on whether U is bigger than Y. The relative sizes of U and Y depend on the slope of D(F). When the D(F) curve is less steep, i.e., when demand is more price elastic, Y will be larger compared to U. When the D(F) curve is steeper, i.e., when demand is more price inelastic, Y will be smaller compared to U. Changes in producer surplus may be negative with increased harvest if demand is sufficiently inelastic.

[10] As described in section A4-8 and Bishop and Holt (2003), the total consumer surplus accumulated through tiered markets can be estimated from a general equilibrium demand function (but not from a more typical single market partial equilibrium demand curve).

becomes determining the relationship between increases in gross revenues and changes in producer surplus, when prices remain constant.

A4-6.1 Producer Surplus as a Percentage of Gross Revenues: Assuming No Change in Prices

Given the potential for increases in producer surplus for the harvest sector (including rents to harvesters) under conditions where fish prices do not change, EPA has estimated producer surplus as a constant fraction of the change in gross revenue. There are at least two relevant cases to consider: the case of unregulated fisheries, and the case of fisheries that are regulated with quotas or restrictive permits.

A4-6.2 Unregulated Fisheries

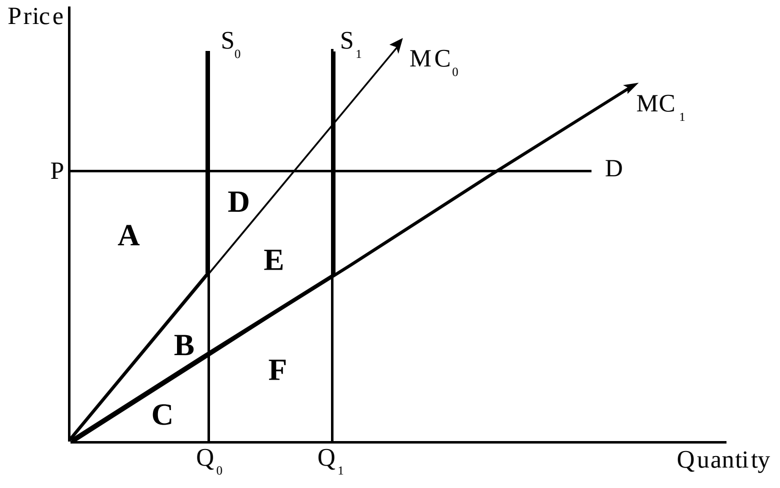
In an unregulated fishery, a reduction in I&E that leads to an increase in the stock of fish will decrease the marginal cost of catching more fish. This makes it possible for fishers to earn economic rents, and for producer surplus to increase. According to basic microeconomic principles, in a competitive market economic rents will attract additional fishing effort in one of two ways: either existing fishers will exert greater effort or new fishers will enter the market (or both). In either case, fishing effort theoretically will increase until a new equilibrium is reached where economic rents are equal to zero. In this case, there may be economic benefits to commercial fishers in the short term, but in the long run producer surplus will be zero. Thus, in an unregulated fishery economic theory suggests that the long-run change in producer surplus will be 0% of the change in gross revenues.

A4-6.3 Regulated Fisheries

Fishery regulations seek to create sustainable harvests that maximize resource rents. In a regulated fishery, reduced I&E that increases the number of fish available to harvest, may lead to increases in harvest, if regulations are relaxed to allow for greater harvest. In this case, unlike the open access case, there will be lasting benefits to commercial fishers.

As an example, assume that quotas are the regulatory instrument, that quotas increase (from Q_0 to Q_1) in response to reduced I&E, and that the supply curve (as represented by a marginal cost curve) shifts as a result of increased stock (from S_0 to S_1). Then, we can relate the change in producer surplus to the change in gross revenue, as illustrated in Figure A4-4. Before the increase in stock and change in quota, producer surplus is equal to area A. After the increase in stock and change in quota, producer surplus is equal to area (A + B + D + E). The change in producer surplus resulting from the increased quota is therefore equal to area (B + D + E).

Figure A4-4: Surplus in a Regulated Fishery Where Price is Constant



Before the increase in stock and change in quota, total revenue is equal to area (A + B + C). After the increase in stock and change in quota, total revenue is equal to area (A + B + C + D + E + F). The change in total revenue resulting from the increased quota is therefore equal to area (D + E + F). Therefore, the relationship between the change in producer surplus and the change in total revenue depends on the relative magnitudes of areas B and F.

Three scenarios illustrate how the change in total revenue may over- or under-estimate the change in producer surplus:

1. If $B < F$, then the change in revenue over-estimates the change in producer surplus.
2. If $B = F$, then the change in revenue approximates the change in producer surplus.
3. If $B > F$, then the change in revenue underestimates the change in producer surplus.

Note that if the first scenario prevails, then some fraction of gross revenue may be more suitable as a reliable proxy for change in producer surplus when price is assumed constant. If the marginal cost of supplying the extra fish at the higher quota, Q_1, is minimal or close to zero, then the second or third scenarios are likely, and 100% or more of the change in revenue may serve as a reliable proxy for the change in producer surplus.

A4-6.4 Conclusions on Surplus When No Change in Price is Anticipated

Various scenarios may arise when fishery conditions improve such that supply increases without generating a price change of consequence. When prices do not change, there is no anticipated change in post-harvest surplus to consumers or other post harvest entities, because a reduction in price is required to generate such changes. Hence, under these conditions, the change in economic welfare is limited to changes in producer surplus.

As shown in the previous section, estimates of changes in dockside revenues become, under some scenarios, equivalent to the change in producer surplus. Hence, the change in gross revenues can be used as a proxy to estimate the change in producer surplus for the regional analyses.[11] EPA also recognizes that under some of the possible scenarios that may arise when there is a quota-governed market, the full change in revenues (as estimated through a projected change in landings but no price change) might overstate the change in producer surplus. However, if dockside prices and/or dockside landings (quantities) are understated — as may often be the case — then the change in surplus will be understated in most scenarios when approximated by the estimated change in gross revenues.

EPA’s analysis of commercial fishery benefits relies on the premise that the change in producer surplus is a fraction of the projected change in revenues. EPA estimated a species- and region-specific fraction, providing a range of 0% to 84%. The lower estimate of 0% represents the case of an unregulated fishery, as well as is the lower bound identified in the literature. This is described in greater detail in section A4-10.

A4-7 Surplus Estimation Under Scenarios in Which Price May Change

In the preceding section, the discussion was limited to cases in which no notable change in price was anticipated. These scenarios appear reasonable for very small improvements in fishery conditions, which is relevant for the regional analyses. If the estimated impacts were larger, as may be the case in other analyses, it may be inappropriate to assume that there will be no price effects in any commercial fishery markets. This section discusses the conceptual and empirical basis for estimating economic surplus (i.e., benefits) in instances where price changes are more likely to arise.

---

[11] This is consistent with EPA’s guidelines (U.S. EPA, 2000a). The guidelines describe options for estimating ecological benefits for fisheries, and note that “if changes in service flows are small, current market prices can be used as a proxy for expected benefit . . . a change in the commercial fish catch might be valued using the market price for the affected species” (p. 98).

A4-7.1 Neoclassical Economic Perspective on the Market and Economic Welfare

Figure A4-2 and section A4-4.3 described the standard, neoclassical economic depiction of a market, with demand downward sloping and supply upward sloping to reflect increasing marginal costs. There are several reasons why this neoclassical depiction may not be directly applicable to the commercial fisheries market, as discussed later in this chapter. But for the moment, Figure A4-2 and the related discussion provide a useful starting point for considering how the measures of economic benefit — the sum of producer and consumer surplus — might change due to a policy that shifts the supply curve outward from S_0 to S_1.

As noted previously, a portion of the gain in consumer surplus (represented by area B in Figure A4-2) is, in effect, a transfer from producer surplus. Any empirical effort to estimate changes in surplus needs to ensure that if change in total surplus is included in the estimate of post-harvest surplus, then the producer surplus estimate should be made net of this quantity to ensure no double counting.[12]

Other noteworthy observations, as discussed in section 4-4.3, are that, under some circumstances, the change in revenues may be zero or even negative and the change in producer surplus can be positive or negative. Even with the transfer of area B from producer to consumer surplus, there are still positive net gains in producer surplus if F + G > B.

A4-7.2 Issues in Estimating Changes in Welfare

The discussion above regarding welfare measures — and how they change with shifts in supply within the neoclassical framework — is fairly complex, even in its simplest form. To estimate such changes in welfare as may arise from the regulatory analysis options for the section 316(b) regulation, the problem becomes even more complicated. Some of the empirical and conceptual complications are discussed below.

In an expedited regulatory analysis that must cover a broad range of fish species across locations and fishery markets that span the nation, EPA must rely on readily applicable generalized approaches (rather than more detailed, market-specific assessments) to estimate changes in welfare. Hence, as noted earlier in this chapter, EPA must rely on readily estimated changes in gross revenues and from there infer potential changes in post-harvest (consumer) and producer surplus. Also, there are several issues associated with how to implement an expedited approach.

First, there is the issue of how to estimate the change in gross revenues. These changes in revenues are the product of the projected changes in fish harvests times observed baseline market prices. Thus, EPA can readily obtain an estimate comparable to the area Y + Z + A + B in Figure A4-5. This is the approach contemplated by the Agency for this rulemaking to handle the case in which prices change. To more suitably capture the impact of a price change, in future analyses EPA may attempt to apply an applicable estimate of price elasticity to obtain an estimate that better reflects the true measure of the change in gross revenues (i.e., areas Y + Z - U - V in Figure A4-5).

Second, there is the issue of how to infer changes in post-harvest (consumer) surplus based on changes in revenues. The approach described by Bishop and Holt (2003), described in greater detail in section A4-8, is specifically designed to examine this issue. Their empirical research — limited to date to some regions and fisheries (e.g., the Great Lakes) — suggests that the changes in post-harvest surplus may be approximated by the estimated change in

---

[12] Later in this chapter an approach developed by Bishop and Holt (2003) to estimating post-harvest surplus as depicted by areas B + C + D is described. Also, note that if the fishery in question is being conducted under open access, this means that rents to the resource are zero or very close it. Suppose furthermore that in this particular case other rents (e.g., rents to scarce fishing skills and knowledge) are also zero. Now suppose that section 316(b) regulatory analysis options are imposed on Phase III facilities, causing an increase in the harvest of fish. The catch increases, but any effects on rents to the resource are dissipated by entry. The effect of the regulatory analysis options is to increase consumer surplus by an amount comparable to areas U + V + B in Figure A4-5, but there is no offsetting decline in producer surplus because there was no producer surplus in the first place.

gross revenues (where the latter is based on holding price constant at baseline levels). This method may also be revisited by EPA in future analyses.

Third, there are a series of issues associated with how to estimate the change in producer surplus. Estimating the change in producer surplus under a scenario in which market forces produce a price change is a challenging exercise for a number of reasons, including:

- Many commercial fishery markets do not adhere to the usual assumptions of the neoclassical model because of regulations that establish harvest quotas and/or restrict entry through a permit system. These regulations typically are instituted to protect stocks that have been or are at risk of being over-fished. There also may be nonregulatory barriers to entry that affect this market, such as the high fixed costs and specialized knowledge and skills required to effectively compete in some fisheries.

- Barriers to entry, regardless of the source, can have a profound impact on the economic welfare analysis. For example, the neoclassical model of open access would have rents driven to zero, but it is more likely in regulated markets (or a nonregulated market with economic barriers to entry) that there are positive rents accruing from the fishery resource (not to mention rents that accrue as well to specialized fishing skills and knowledge).[13]

- Empirical evidence regarding the absolute magnitude of producer surplus is limited (especially for inferring a relationship with gross revenues). However the approach described earlier succeeded in assessing a region and species-specific proxy for a relationship between producer surplus and gross revenue. The proxy is based on a ratio between normal profits and gross revenue and is called the net benefits ratio (NBRatio). However, interpreting the assessed ratio properly is challenging, for a number of reasons:
  - Available empirical data pertain to average producer surplus, and EPA's regulatory analysis must instead address changes in producer surplus at the margin.
  - The portion of producer surplus that is transferred to consumers when there is a price reduction (represented by area U in Figure A4-5) should not be double-counted if it is captured in the estimate of post-harvest surplus and also in the estimated change in producer surplus. Since area U is included in the Bishop-Holt analysis of changes in post-harvest surplus, one needs to ensure that area U is not included in (e.g., has been netted out of) the applicable estimate of the change in producer surplus.
  - The estimated empirical relationship between normal profits and gross revenue needs to be adjusted downwards to depict accurately the relationship between producer surplus and gross revenue. Limited empirical evidence is available for such an adjustment, but seems to point to a range between 0.4 and 2.6% (U.S. EPA, 2004e).

It is important to address these issues here because of the manner in which the departure from the neoclassical model affects the interpretation of estimates of average producer surplus relative to changes expected at the margin. For example, marginal costs (MC) for commercial fishers may be minimal for a small increase in landings arising from a small increase in harvestable fish — for small increases in numbers of fish suitable for harvest in an area, small increases in harvest are likely to be realized with minimal added operating expense (i.e., MC at or near zero). This might arise where the fishers fill their quotas more easily, or exert essentially the same level of effort but come back with a few more fish. Where fishing effort and hence fishing costs would not change much, benefits (producer surplus) would equal the change in total revenue or be very close to it. For larger changes, marginal and average costs could shift down.

---

[13] Given the highly regulated nature of many fisheries today, a wide range of producer effects is conceivable. Even where revenues decline with a reduction in price, producer surplus could increase despite the loss in revenues. This could occur if the effect on price is relatively small and the effect on costs and revenues is relatively large. The only way to know for sure is to examine producer effects in specific cases or do a benefit transfer exercise using experience in real world fisheries as a guide. Simple approaches (e.g., assuming that there is no consumer surplus because of offsetting producer effects) are not satisfactory if there are changes in prices.

This has implications for interpreting the estimated NBRatios. The standard neoclassical model assumes increasing MC in the relevant range, so that producer surplus approaches zero with additional increments in landings. But for the type of situation that applies to section 316(b) — i.e., with a small change in the harvestable number of fish — and given the nature of the commercial fishery (e.g., high barriers to entry due to quotas or high fixed costs), the context is likely to reflect a situation in which costs decrease (e.g., a shift downward in MC, and perhaps MC that are at or near zero). If so, then the argument that the average estimate for producer surplus overstates the marginal value does not hold (in fact, the opposite may be true — average surplus could be less than producer surplus at the margin).

A4-8 Estimating Post-Harvest Economic Surplus in Tiered Markets

Producer surplus provides an estimate of the benefits to commercial fishers, but significant benefits can also be expected to accrue to final consumers of fish and to commercial consumers (including processors, wholesalers, retailers, and middlemen) if the projected increase in catches is accompanied by a reduction in price. These benefits can be expected to flow through the tiered commercial fishery market (as described in section A4-1 and in Bishop and Holt, 2003).

Bishop and Holt (2003) develop an inverse demand model of six Great Lakes fisheries that they use to estimate changes in welfare as a result of changes in the level of commercial harvest. This flexible model can be used to estimate welfare changes under a variety of conditions in the fishery. It takes as an input the expected change in harvest and baseline gross revenues, and provides as outputs the expected change in gross revenues and change in total compensating variation (CV).

CV is the change in income that would be necessary to make consumers' total utility the same as it was before the reduction in I&E losses resulting from the regulatory analysis options for the final section 316(b) rule for Phase III existing facilities. This is analogous to a measure of willingness to accept compensation in order to forgo the improvement. Conceptually, CV is a measure of welfare similar to consumer surplus. The key difference is that consumer surplus is calculated using the familiar demand function (or curve), which defines the quantity demanded as a function of price and income (in the simple example, Figures A4-1 and A4-2, income is assumed to be constant). CV, on the other hand, is calculated using a compensated demand function, which defines the quantity demanded as a function of price and utility. While consumer surplus and CV are generally very similar welfare measures, CV is considered to be the true measure of benefits (i.e., a more consistent indicator of utility), and consumer surplus is an approximation. The distinction between the two is a subtle point in welfare economics; the exact details are not crucial to the analysis.[14]

The key point to note is that estimates of CV from the Holt-Bishop model capture the benefits to final consumers and commercial consumers throughout the various markets in which fish are bought and resold for a given level of harvest. The model output provides a convenient way to estimate the benefits of an increase in harvest as a percentage of gross revenues, and thus a tractable way to estimate the benefits of increased catch that do not accrue to the primary producers.[15] See Holt and Bishop (2002) for further detail on the model.

Based on comments received on the commercial benefits analysis for the final Phase II rule, EPA worked with Dr. Bishop to re-assess the suitability of using the results from Holt and Bishop (2002) in a benefit transfer. EPA determined that the magnitude of the changes in commercial catch modeled in the Holt and Bishop paper is, in most cases, larger than the magnitude of the expected changes as a result of the Phase II and Phase III regulations,

---

[14] For a more detailed discussion of the difference in consumer surplus and CV, the reader is referred to in Varian (1992, Chapters 7 and 9) or any graduate-level microeconomics text.

[15] Bishop and Holt do not estimate changes in producer surplus, and indicate such changes need to be estimated separately and then combined with post-harvest consumer surplus results.

and thus the benefits may be quite different. To address this issue, Bishop and Holt (2003) explore the impacts on surplus measures for more moderate changes in fishery conditions, by reestimating their Great Lakes model, relating economic surplus to levels of gross revenues.

In this more recent work, Bishop and Holt (2003) observe that, as a general rule of thumb, based on their analysis of the Great Lakes fisheries, the change in CV as a percentage of the change in gross revenues is more or less linearly related to the change in catch. In other words, 10% increase in catch as a result of the regulatory analysis options for Phase III facilities would be expected to produce an increase in CV equal to approximately 10% of the change in gross revenues. As an example, if the regulatory analysis option for Phase III facilities increases the catch of a species by 10% and the gross value of the additional catch is $100,000, then the increase in CV would be $10,000.

Since the increase in commercial fishing yield is small and no significant price changes are expected, no significant change in CV is expected. In estimating benefits, EPA has assumed the change will be $0.

A4-9 Nonmonetary Benefits of Commercial Fishing

As with many activities, commercial fishing provides benefits that are not measured in the value of the catch. Fishing is difficult and dangerous work. It involves strenuous outdoor work, long hours, and lengthy trips to sea, often in hazardous weather conditions. “Fishing has consistently ranked as the most deadly occupation since 1992,” when the Bureau of Labor Statistics (BLS) started publishing fatality rates by occupation (Drudi, 1998, p. 1). In addition, the BLS Occupational Handbook: Fishers and Fishing Vessel Operators (U.S. Bureau of Labor Statistics, 2002) predicts that “employment of fishers and fishing vessel operators is expected to decline through the year 2010. These occupations depend on the natural ability of fish stocks to replenish themselves through growth and reproduction, as well as on governmental regulation of fisheries. Many operations are currently at or beyond maximum sustainable yield, partially because of habitat destruction, and the number of workers who can earn an adequate income from fishing is expected to decline.”

In spite of this, individuals still express a desire to fish, perhaps even because of the hardships and challenges of the job. Studies on why fishers choose to fish have determined that income is, not surprisingly, the primary reason for participating in commercial fishing. Fishers fish to support themselves and their families, and generally earn more in fishing than they would in other occupations. There are other important factors, though, including the importance of fishing to the way of life in small, coastal towns (not unlike the importance of farming to many rural towns throughout the United States); the belief that fishing helps the U.S. economy; and identity, i.e., people opt to work in commercial fishing because it provides enjoyment and because it is an integral part of how they identify themselves psychologically and socially (Smith, 1981; Townsend, 1985; Berman et al., 1997).

Research in the economic literature indicates that some fishers opt to remain in the fishing industry despite the ability to make higher incomes in other industries. Some economists have suggested that there exists a worker satisfaction bonus that can, at least in theory, be measured and should be included in cost-benefit analyses when making policy decisions (Anderson, 1980). One study identified in a cursory literature review of this topic also found evidence in the Alaskan fisheries that as many as 29.5% of all vessels across 14 fisheries from 1975 to 1980 earned net incomes that were lower than the income they could receive from selling their fishing permit. The author concluded that “this pattern of apparent losses seems to confirm much of the casual observation that is the source of speculation that non-pecuniary returns are a significant factor in commercial fishing. It is thought that these financial losses are accepted only because they are offset by non-money gains” (Karpoff, 1985).

Because the Alaskan fisheries exist under much different conditions than those in the rest of the United States, it would be a mistake to assume that nearly 30% of U.S. fishing vessels earn incomes less than the value of their fishing permits. However, based on EPA’s review of the commercial fishing literature, there is evidence that commercial fishers gain nonmonetary benefits from their work. Despite the existence of these nonmonetary benefits in the commercial fishing sector, there is little research that has provided defensible methods for estimating the additional nonmonetary benefits that may accrue to commercial fishers as a result of the regulatory analysis options for the final section 316(b) rule for Phase III facilities. Thus, the omission of these nonmonetary benefits is noted here, but no estimates will be included in the benefits analyses.

A4-10 Estimating Producer Surplus

A4-10.1 Introduction

In theory, producer surplus is equal to normal profits (total revenue minus fixed and variable costs), minus opportunity cost of capital. However, reduced I&E-related fish deaths do not in the short run affect the level of fixed inputs because fixed costs and inputs are incurred independent of the expected marginal increase in the level of I&E-induced landings (personal communication; E. Tsongburg and E. Squires, 2/18/2005; D. Haksever, 7/26/2005). Variable costs such as ice and other supplies, however, directly vary with the level of landings. Furthermore, since opportunity cost of capital is estimated only to be about 0.4 to 2.6% of producer surplus, normal profits are assumed a sufficient proxy for producer surplus (U.S. EPA, 2004e). As a result, assessment of producer surplus, or net benefits, of I&E-induced reductions in fish deaths and its corollary increase in landings is reduced to a relatively straightforward calculation in which the change in producer surplus is calculated as a species- and region-specific fraction of the change in gross revenue due to increased landings. Thus EPA assumed that fixed inputs, such as the number of vessels, are not affected by increased landings.

A4-10.2 Methodology

❖ ***If cost data are available***

When comprehensive data on variable costs in a fishery were readily available, EPA derived species- and region-specific net benefits directly from the product of species-specific NBRatios (see below) and species-specific gross revenue resulting from the regulation-induced increase in landings. Gross revenue is a function of total landings and ex-vessel price per unit of landed fish. The methodology is based on the following assumptions:

1. Fishing mortality is constant and fishers increase their fishing activity in response to increased availability of fish, with a consequent increase in fish landings.
2. The increase in landings is a linear function of reduced I&E. Reduced I&E mortality thus directly results in increased landings.
3. Current dockside prices per ton of catch remain constant and are not affected by increased catch.
4. The relationship between variable cost (VC) or alternatively, producer surplus, and gross revenue remains constant (see e.g., NEFMC, 2003).
5. Fixed costs (FC) remain constant, and will not change as a result of the regulation.
6. Assuming constant dockside prices, there is no regulation-induced change in consumer surplus.
7. The derived relationship between gross revenue and producer surplus, assuming no regulation-induced change in fixed costs, is assumed to be constant.

Following the conventional method used by NMFS fishery economists (personal communication; E. Tsongburg and E. Squires, 2/18/2005; D. Haksever, 7/26/2005), EPA estimated net benefits, or the increase in producer surplus, from reduced I&E-induced fish deaths using the ratio between gross revenue and normal profits as a proxy for the initial producer surplus (equal to gross revenue minus VC), multiplied by the regulation-induced increase in gross revenue.

❖ *Cost variable definitions*

Variable cost (VC) consists of the following nine variable cost items, which are collected by region, gear and vessel size. EPA calculated each of the following items as the cost of the item purchased per trip:

1. *Bait*
2. *Food*
3. *Fuel*
4. *Ice*
5. *Lubricating oil*
6. *Water*
7. *Damages*
8. *Supplies*
9. *Labor*: Assessed per trip as a function of total size of crew per trip, average length of trip and based on the mean regional wage for "Fishers and Related Fishing Workers" as assessed by the U.S. Department of Labor.

EPA then assessed total variable cost (TVC) per trip as the sum of each of the nine VC variables, to estimate TVC per trip by boat size and gear type for each region. The cost values for both the North and Mid-Atlantic are derived from the fishery observer program (http://www.nefsc.noaa.gov/femad/fishsamp/fsb/), and gross revenue per trip is from the NMFS Northeast Region Commercial Dealer database. Cost and revenue values for the South Atlantic and Gulf of Mexico were provided by Larry Perruso at the South Atlantic Fisheries Science Center and based on The Federal Logbook Trip Report Form, in addition to specific data on the shrimp fishery in the Gulf of Mexico provided by Jim Waters, also at the South Atlantic Fisheries Science Center. Cost and revenue data for California were derived from King and Flagg (1984) and Caroline Pomeroy at California Sea Grant.

❖ *Joint variable and fixed costs*

Fixed and variable costs that are jointly shared among various species, which are caught using the same vessel and gear, and often during the same trip, must be allocated among species to realize variable cost per species. To allocate those costs among the appropriate species, the "Use of Facilities Method" was recommended by Squires et al. (1998) and Eric Tsongburg at the National Marine Fisheries Science Center in Woods Hole, MA (personal communication; E. Tsongburg, 8/2/2005). This approach allocates the joint costs based on the relative quantity of landings (measured in pounds) for each species by boat (small, medium, large) and gear type. However, due the nature of available data, EPA used a variant of the "Use of Facilities Method" (see below). As stated before, EPA assumes that fixed costs remain constant. Therefore fixed costs are excluded from the analysis.

❖ *Net benefits ratio calculation*

The calculation of regulation-induced NBRatio by region, gear and vessel type is based on Equation 1. Assuming that price and AVC per ton stay constant over time (or move at the same rate), the assessment of net benefits reduces to an assessment of a NBRatio per vessel size and gear type (Equation 1)[16]:

$$NBRatio_{i,trip} = (1 - (\frac{TVC_{i,trip}}{\sum_{s=1}^{x} PEX_{s,t} * LN_{i,s,trip}})) \qquad \text{(Equation 1)}$$

---

[16] Each assessment is region-specific. Region-specific notation is suppressed to increase clarity.

where:

NBRatio = the fractional share of gross revenue associated with net benefits, by gear and vessel type
i = gear and vessel type
trip = fishing trip
TVC = total variable cost per trip in US$ 2004, by vessel size and gear type
PEX = ex-vessel price per pound of species *s*, at time *t* in US$ 2004
s = individual species, measured in pounds
t = time
LN = landings per species *s*, per trip, in pounds

As stated above, each fish species is caught using various types of vessels and gear. As a result, a species-specific NBRatio is developed as a weighted average of all gear specific NBRatios that are used to catch that particular species (Equation 2):

$$NBRatio_s = \sum_{i=1}^{x} \left(NBRatio_{i,trip} * \frac{LN_{s,i}}{\sum_{i=1}^{x} LN_s}\right) \qquad \text{(Equation 2)}$$

where:

NBRatio_s = the fractional share of gross revenue associated with net benefits, by species *s*
LN = landings per species *s*, per trip, in pounds
s = individual species, measured in pounds
i = gear and vessel type

Net benefits or producer surplus per fish species is then assessed as the product of the species-specific NBRatio and gross revenue.

❖ ***If cost data are not available***

When cost data were not available for individual species, EPA indirectly derived the NBRatio from other regions and/or species relying on the region and species-specific NBRatios. EPA transferred the NBRatio based on similarity of attributes, such as harvesting and management methods. In the case of species aggregates (e.g., forage species), EPA assumed that the net benefit ratio is equal to the simple average of all empirically estimated net benefit ratios in the region.

A4-10.3 Region-Specific Estimates of Net Benefits Ratios

❖ ***North Atlantic region***

Table A4-4 summarizes, for each fish species, applicable information underlying the estimates of NBRatios for the North Atlantic region.

The results indicate that the NBRatios range from 0 to 0.82, depending on species, indicating that net benefits range from 0 to 82% of the regulation-induced increase in gross revenue. Since variable cost data are not available for traps and various hand lines in the North Atlantic region, the NBRatio is based on data from the Mid- and South Atlantic region for crabs, American shad, tautog, and weakfish. The NBRatio for species managed as “open access” such as lumpfish, sculpins, and searobin are assumed to equal zero.

Table A4-4: North Atlantic Region, Species-Specific Gear Type, Status of Stock, and NBRatio

Fish Species	Main Management Method	Main Gear Type	Status of Stock	Net Benefits as a ratio of Gross Revenue (NBRatio)
American plaice	Quota	Otter trawl, gill net	Over-utilized	0.63
American shad	Open access	Otter trawl, gill net, traps	N/A	0.60
Atlantic cod	Quota	Otter trawl, gill net, hook	Over-utilized	0.66
Atlantic herring	Quota	Purse seine, midwater trawl	Under-utilized	0.76
Atlantic mackerel	Quota	Midwater trawl, otter trawl	Under-utilized	0.77
Atlantic menhaden	Open access	Purse seine, gill net	Full	0.68
Bluefish	Quota	Otter trawl, gill net	Over-utilized	0.63
Butterfish	Quota	Otter trawl	Under-utilized	0.64
Crabs	Quota	Traps	Unknown	0.57
Lumpfish	Open access	Otter trawl	Unknown	0.00
Pollock	Quota	Otter trawl, gill net, long lines	Full	0.71
Red hake	Quota	Otter trawl, gill net	Over-utilized	0.62
Sculpins	Open access	Otter trawl	Unknown	0.00
Scup	Quota	Otter trawl, gill net, long lines	Over-utilized	0.69
Searobin	Open access (by catch)	Floating traps, otter trawl	Unknown	0.00
Silver hake	Quota	Otter trawl, gill net	Over-utilized	0.63
Skates	Open access — w/ size restrictions	Otter trawl, gill net	Under-utilized	0.68
Tautog	Quota	Otter trawl, gill net, hand lines	Over-utilized	0.46
Weakfish	Days at sea	Otter trawl, gill net, floating traps	Full	0.76
White perch	Open access	Gill net	Under-utilized	0.82
Windowpane	Quota	Otter trawl, gill net	Over-utilized	0.63
Winter flounder	Quota	Otter trawl, gill net	Over-utilized	0.64
Other (forage)	N/A	N/A	N/A	0.57

❖ *Mid-Atlantic region*

Table A4-5 summarizes, for each fish species, applicable information underlying the estimates of NBRatios for the Mid-Atlantic region.

The results indicate that the NBRatios range from 0.57 to 0.85, depending on species, indicating that net benefits range from 57 to 85% of the regulation-induced increase in gross revenue. Since variable cost data are not available for traps and various hand lines, the NBRatio for crabs, striped bass, and white perch are based on data from the South and North Atlantic.

In the Mid-Atlantic region, none of the affected species is considered to be managed as purely "open access" since all have a defined management body and, as a result, could be converted to a different management regime.

Table A4-5: Mid-Atlantic Region, Species-Specific Gear Type, Status of Stock, and NBRatio

Fish Species	Main Management Method	Main Gear Type	Status of Stock	Net Benefits as a % of Gross Revenue (NBRatio)
Alewife	Open access (by catch)	Gill net	Over-utilized	0.85
American shad	Open access	Gill net	Over-utilized	0.84
Atlantic croaker	Open access (by catch)	Otter trawl, gill net	Over-utilized	0.74
Atlantic menhaden	Open access	Purse seine, otter trawl, gill net	N/A	0.67
Blue crab	Size	Traps	Unknown	0.57
Other (commercial)	N/A	N/A	N/A	0.73
Other (commercial and recreation)	N/A	N/A	N/A	0.73
Spot	Open access (by catch)	Gill net	Unknown	0.84
Striped bass	Quota	Gill net, otter trawl, hand lines	Full	0.67
Summer flounder	Quota	Otter trawl, long lines, gill net	Over-utilized	0.65
Weakfish	Per trip quota	Otter trawl, long lines, gill net	Full	0.76
White perch	Open access	Otter trawl, long lines, gill net, purse seines	Under-utilized	0.82
Windowpane	Quota	Otter trawl, gill net	Over-utilized	0.70
Winter flounder	Quota	Otter trawl, gill net	Over-utilized	0.70
Other (forage)	N/A	N/A	N/A	0.73

❖ *South Atlantic region*

Table A4-6 summarizes, for each fish species, applicable information underlying the estimates of NBRatios for the South Atlantic region. The results indicate that the NBRatios range from 0.39 to 0.76, depending on species, indicating that net benefits range from 39 to 76% of the regulation-induced increase in gross revenue.

In the South Atlantic region, none of the affected species is considered to be managed as purely "open access" since all have a defined management body and, as a result, could be converted to a different management regime.

Table A4-6: South Atlantic Region, Species-Specific Gear Type, Status of Stock, and NBRatio

Fish Species	Main Management Method	Main Gear Type	Status of Stock	Net Benefits as a Ratio of Gross Revenue (NBRatio)
Alewife	Open access (by catch)	Pound nets, gill nets	Over-utilized	0.70
American shad	Open access (by catch)	Gill nets	Over-utilized	0.73
Atlantic croaker	Open access (by catch)	Otter trawl bottom, gill nets	Over-utilized	0.54
Atlantic menhaden	None	Purse seines, gill nets	Full	0.76
Black drum	None	Pound nets, gill nets	Unknown	0.70
Blue crab	Size limits	Pots and traps	Full	0.57
Leatherjacket	Trip limits	Hand lines, other; reel, electric or hydraulic	Unknown	0.39
Mackerels	Quotas	Hand lines, gill nets, troll lines	Under-utilized	0.66
Menhadens	Open access	Purse seines, gill nets	Full	0.75
Sea basses	Limited access permit	Pots and traps, trawl	Unknown	0.50
Sheepshead	Limited access permit	Cast nets, hand lines	Unknown	0.60
Shrimp	Limited access permit, area closures	Trawls	Full	0.44
Spot	Open access (by catch)	Gill nets, haul seines	Over-utilized	0.70
Stone crab	Size limits	Pots and traps	Unknown	0.58
Striped bass	Quota	Gill nets, haul seines	Full	0.67
Striped mullet	Gear and size restrictions	Gill nets, drift, runaround; cast nets	Unknown	0.70
Summer flounder	Quota	Trawl	Over-utilized	0.43
Weakfish	Seasonal closures — trip limits	Gill nets, otter trawl	Full	0.64
Windowpane	Seasonal closures — trip limits	Trawl	Over-utilized	0.43
Other (forage)	N/A	N/A	N/A	0.59

❖ *Gulf of Mexico region*

Table A4-7 summarizes, for each fish species, applicable information underlying the estimates of NBRatios for the Gulf of Mexico region.

As reported in Table A4-7, NBRatio estimates range from 0 to 0.79, depending on species, indicating that net benefits range from 0 to 79% of the regulation-induced increase in gross revenue. The NBRatio for species managed as “open access” such as Atlantic croaker, leatherjacket, spot, and sheepshead are assumed to equal zero.

Table A4-7: Gulf of Mexico Region, Species-Specific Gear Type, Status of Stock, and NBRatio

Fish Species	Main Management Method	Main Gear Type	Status of Stock	Net Benefits as a Ratio of Gross Revenue (NBRatio)
Atlantic croaker	N/A	Combined gear	Over-utilized	0.00
Black drum	Limited access permits	Hand lines, gill nets	Unknown	0.69
Blue crab	Limited access permits	Pots and traps	Unknown	0.72
Leatherjacket	N/A	Rod/reel, hand and long lines, pots and traps	Unknown	0.00
Mackerels	Quotas	Hand lines, gill nets	King-over-utilized Spanish-fully-utilized	0.75
Menhaden	Seasonal/area closures	Purse seines	Fully-utilized	0.76
Other (commercial)	N/A	N/A	N/A	0.46
Shrimp	Quotas	Otter trawl	Fully-utilized	0.43
Sea basses	Limited access permits	Pots and traps	Unknown	0.72
Sheepshead	N/A	Gill nets	Unknown	0.00
Spot	N/A	Gill nets	Unknown	0.00
Stone crab	Seasonal closures	Pots and traps	Fully-utilized	0.71
Striped mullet	Total allowable catch	Gill nets, cast nets	Unknown	0.79
Other (forage)	N/A	N/A	N/A	0.46

❖ *California region*

Table A4-8 summarizes, for each fish species, applicable information underlying the estimates of NBRatios for the California region.

As reported in Table A4-8, NBRatio estimates range from 0.00 to 0.74, depending on species, indicating that net benefits range from 0 to 74% of the regulation-induced increase in gross revenue. The NBRatio for species managed as “open access” such as American shad, is assumed to equal zero.

Table A4-8: California Region, Species-Specific Gear Type, Status of Stock, and NBRatio

Fish Species	Main Management Method	Main Gear Type	Status of Stock	Net Benefits as a Ratio of Gross Revenue (NBRatio)
American shad	None	Nets	Unknown	0.00
Anchovies	Total allowable catch	Nets	Under-utilized	0.64
Cabezon	Quotas	Gill nets, nets excluding trawls, hand lines, pots and traps	Unknown	0.52
California halibut	Total allowable catch	Nets excluding trawls, trawls	Under-utilized	0.58
California scorpionfish	Quotas	Otter trawl bottom	Unknown	0.47
Commercial sea basses	Seasonal closures — prohibited species	Nets excluding trawls	Unknown	0.66
Commercial shrimp	Seasonal closures	Otter trawl bottom, trawls	Fully-utilized	0.15
Commercial crabs	Seasonal closures	Pots and traps	Fully-utilized	0.74
Drums croakers	Permits — prohibited species	Nets excluding trawls, gill nets	Unknown	0.42
Dungeness crab	Seasonal closures	Pots and traps	Fully-utilized	0.74
Flounders	Quotas	Trawls, otter trawl bottom	Under-utilized	0.64
Northern anchovy	Total allowable catch	Nets excluding trawls	Under-utilized	0.64
Rockfishes	Quotas	Otter trawl bottom, hand lines, trawls	Fully-utilized	0.62
Sculpins	Nonrestrictive permits	Trawls	Under-utilized	0.64
Smelts	Seasonal closures	Nets excluding trawls	Fully-utilized	0.66
Surfperches	Quotas	Hand lines	Over-utilized	0.37
Other (forage)	N/A	N/A	N/A	0.53

❖ *Great Lakes region*

Table A4-9 summarizes, for each fish species, applicable information underlying the estimates of NBRatios for the Great Lakes region. As reported in Table A4-9, NBRatio estimates are equal to 0.29 indicating that net benefits equal 29% on average of the regulation-induced increase in gross revenue.

Table A4-9: Great Lakes Region, Species-Specific Gear Type, Status of Stock, and NBRatio

Fish Species	Main Management Method	Main Gear Type	Status of Stock	Net Benefits as a ratio of Gross Revenue (NBRatio)
Black bullhead	State specific	Gill and trap nets	Unknown	0.29
Brown bullhead	State specific	Gill and trap nets	Unknown	0.29
Bullhead species	State specific	Gill and trap nets	Unknown	0.29
Channel catfish	State specific	Gill and trap nets	Unknown	0.29
Crab	State specific	Gill and trap nets	Unknown	0.29
Flounder	State specific	Gill and trap nets	Unknown	0.29
Freshwater drum	State specific	Gill and trap nets	Unknown	0.29
Menhaden species	State specific	Gill and trap nets	Unknown	0.29
Pink shrimp	State specific	Gill and trap nets	Unknown	0.29
Rainbow smelt	State specific	Gill and trap nets	Unknown	0.29
Sculpin species	State specific	Gill and trap nets	Unknown	0.29
Smelt	State specific	Gill and trap nets	Unknown	0.29
White bass	State specific	Gill and trap nets	Unknown	0.29
Whitefish	State specific	Gill and trap nets	Unknown	0.29
Yellow perch	State specific	Gill and trap nets	Unknown	0.29

A4-11 Methods Used to Estimate Commercial Fishery Benefits from Reduced I&E; Summary

EPA estimated the commercial benefits expected under the regulatory analysis options for the final section 316(b) rule for Phase III facilities with the following steps. In steps 1 through 3, EPA estimated total losses under current I&E conditions (or the total benefits of eliminating all I&E). Then, in step 4, EPA applied the estimated percentage reduction in I&E to estimate the benefits expected under each analysis option. Each step is performed for each region in the final analysis.

The steps used to estimate regional losses and benefits are as follows:

1. **Estimate losses to commercial harvest (in pounds of fish) attributable to I&E under current conditions.** EPA modeled these losses using the methods presented in Chapter A1 of Part A of this document. EPA assumed a linear relationship between stock and harvest, such that if 10% of the current commercially targeted stock were harvested, then 10% of the commercially targeted fish lost to I&E would have been harvested, absent I&E. The percentage of fish harvested is based on data on historical fishing mortality rates.

2. **Estimate gross revenue of lost commercial catch.** EPA estimated the value of the commercial catch lost due to I&E using data on landings and dockside price ($/lb) as reported by NOAA Fisheries for the period 1991-2003. These data were used to estimate the total revenue for the lost commercial harvest under current conditions (i.e., the increase in gross revenue that would be expected if all I&E impacts were eliminated).

3. **Estimate lost economic surplus.** The conceptually appropriate measure of benefits is the sum of any changes in producer and consumer surplus. The methods used for estimating the change in surplus depend on whether the physical impact on the commercial fishery market appears sufficiently small such that it is reasonable to assume there will be no appreciable price changes in the markets for the impacted fisheries.
    a. For the regions included in this analysis, it is reasonable to assume no change in price, which implies that the welfare change is limited to changes in producer surplus. This change in producer surplus, captured by "normal profits," is assumed to be equivalent to a fixed proportion of the change in gross revenues, as developed under step 2. EPA estimated species- and region-specific ratios (NBRatios) between producer surplus and gross revenue, as presented in section A4-10. EPA then applied the NBRatio to the estimated lost revenue to estimate total lost economic surplus. This ratio ranges from 0 to 84%.
    b. EPA believes this is an appropriate approach to estimating producer surplus when there are no anticipated price changes. EPA's *Guidelines for Preparing Economic Analyses* (U.S. EPA, 2000a; EPA 240-R-00-003) describes options for estimating ecological benefits for fisheries, and note that "if changes in service flows are small, current market prices can be used as a proxy for expected benefit . . . a change in the commercial fish catch might be valued using the market price for the affected species." This statement indicates that 100% of the gross revenue change, based on current prices, may be a suitable measure of value and this analysis takes a similar approach.

4. **Estimate increase in surplus attributable to the regulatory analysis options.** Once the commercial surplus losses associated with I&E under baseline conditions were estimated according to the approaches outlined in steps 2 and 3, EPA estimated the percentage reduction in I&E at each facility under each regulatory analysis option. This analysis was conducted for each region. EPA computed the increase in gross revenue using the method described in step 2, and then estimated the producer surplus using the fractional approach described in step 3.

A4-12 Limitations and Uncertainties

Table A4-10 summarizes the caveats, omissions, biases and uncertainties known to affect the estimates that were developed for the benefits analysis.

Table A4-10: Caveats, Omissions, Biases, and Uncertainties in the Commercial Benefits Estimates

Issue	Impact on Benefits Estimate	Comments
Change in commercial landings due to I&E is uncertain	Uncertain	Projected changes in harvest may be under-estimated because neither cumulative impacts of I&E over time nor interactions with other stressors are considered.
Some estimates of commercial harvest losses due to I&E under current conditions are not region/species-specific	Uncertain	EPA estimated the impact of I&E in the case study analyses based on data provided by the facilities. The most current data available were used. However, in some cases these data are 20 years old or older. Thus, they may not reflect current conditions.
Effect of change in stocks on landings is not considered	Uncertain	EPA assumed a linear stock to harvest relationship, so that a 10% change in stock would have a 10% change in landings; this may be low or high, depending on the condition of the stocks. Region-specific fisheries regulations also will affect the validity of the linear assumption.
Effect of uncertainty in estimates of commercial landings and prices is unknown	Uncertain	EPA assumes that NOAA landings data are accurate and complete. In some cases prices and/or quantities may be reported incorrectly.

Chapter A5: Recreational Fishing Benefits Methodology

Introduction

EPA used a benefit transfer approach to estimate the welfare gain to recreational anglers from improved recreational fishing opportunities due to reductions in impingement and entrainment (I&E) under the regulatory analysis options considered for the final section 316(b) rule for Phase III existing facilities.

Benefit transfer involves adapting research conducted for another purpose to address the policy questions at hand (Bergstrom and De Civita, 1999). Although primary research methods are generally preferred to benefit transfer methods, benefit transfer is often the second (or only) alternative to original studies due to resource or data constraints. EPA notes that Smith et al. (2002, p. 134) state that ". . . nearly all benefit cost analyses rely on benefit transfers . . .."

For the Phase III analysis, EPA used a benefit transfer approach based on a meta-analysis to evaluate recreational fishing benefits of the regulatory analysis options for all study regions. To validate the meta-analysis results, EPA also used regional random utility models (RUM) of recreational fishing behavior developed for the Phase II analysis to estimate welfare gain to recreational anglers from improved recreational opportunities resulting from reduced I&E of fish species at Phase III facilities. EPA used the RUM approach to validate results for the four coastal regions and the Great Lakes region, but was unavailable for the Inland region because of a lack of data on Inland site characteristics, including baseline catch rates and presence of boat ramps and other recreational amenities. Chapter A11 of the Phase II Regional Analysis document provides a more detailed discussion of the methodology used in EPA's RUM analysis (U.S. EPA, 2004a).

Chapter Contents

A5-1 Literature Review Procedure and Organization A5-2
A5-2 Description of Studies A5-3
A5-3 Meta-Analysis of Recreational Fishing Studies: Regression Model A5-10
  A5-3.1 Meta-Data A5-10
  A5-3.2 Model and Results A5-17
  A5-3.3 Interpretation of Regression Analysis Results A5-20
A5-4 Application of the Meta-Analysis Results to the Analysis of Recreational Benefits of the Section 316(b) Regulatory Analysis Options for Phase III Facilities A5-23
  A5-4.1 Estimating Marginal Value per Fish A5-23
  A5-4.2 Calculating Recreational Benefits A5-26
A5-5 Limitations and Uncertainties A5-26
  A5-5.1 Sensitivity Analysis Based on Krinsky and Robb (1986) Approach A5-27
  A5-5.2 Variable Assignments for Independent Regressors A5-28
  A5-5.3 Other Limitations and Uncertainties A5-28

Benefit transfer methods fall within three fundamental classes: (1) transfer of an unadjusted fixed value estimate generated from a single study site, (2) the use of expert judgment to aggregate or otherwise alter benefits to be transferred from a site or set of sites, and (3) estimation of a value estimator model derived from study site data, often from multiple sites (Bergstrom and De Civita, 1999). Recent studies have shown little support for the accuracy or validity of the first method, leading to increased attention to, and use of, *adjusted values* estimated by one of the remaining two approaches (Bergstrom and De Civita, 1999).

The third class of benefit transfer approaches includes meta-analysis techniques, which have been increasingly explored by economists as a potential basis of policy analysis conducted by various government agencies charged with the stewardship of natural resources.[1] Although there are few generally accepted guidelines for meta-analyses applied to environmental policy, EPA believes that this is a promising methodology for policy evaluation. This chapter describes how EPA applied meta-analysis, which is often cited as a more appropriate means of benefit transfer, to estimate the welfare gain associated with improved recreational catch.

The first step in implementing an "adjusted value" benefit transfer approach is a systematic analysis of the available economic studies that estimate the welfare gain associated with improved recreational catch. The Agency identified 48 valuation studies that use stated preference or revealed preference techniques to elicit benefit values for changes in recreational catch. All of these studies provide estimates of the marginal value to fishers of catching an additional fish, or provide sufficient information for EPA to calculate such a value. These studies vary in several respects, including valuation methodology, survey administration method, species targeted by anglers, baseline catch rate, location, and economic and demographic characteristics of the sample.

To examine the relative influence of study, economic, and resource characteristics on willingness-to-pay (WTP) for catching an additional fish, the Agency conducted a regression-based meta-analyses of 391 estimates of WTP (or marginal value) per fish, provided by the 48 original studies. The estimated econometric model can be used to calculate per fish values for species that are potentially affected by I&E.

The following discussion summarizes the results of EPA's analysis of recreational fishing studies and outlines the methodology for applying meta-regression results to the estimation of benefits from reduced I&E attributable to the regulatory analysis options.

A5-1 Literature Review Procedure and Organization

EPA performed an in-depth search of the economic literature to identify valuation studies that estimate — or provide sufficient information to calculate — the value that anglers place on catching an additional fish. EPA used a variety of sources and search methods to identify relevant studies:

- review of EPA's research and bibliographies dealing with the recreational benefits of fishing;
- systematic review of recent issues of resource economics journals (e.g., *Land Economics*, *Journal of Agricultural and Resource Economics*, *Journal of Environmental Economics and Management*, *Water Resources Research*);
- searches of online reference and abstract databases [e.g., Environmental Valuation Resource Inventory (EVRI), the Fish and Wildlife Service's Database of Sportfishing Values];
- queries to academic search engines (e.g., EconLit, ISI Web of Science, Index of Digital Dissertations);
- visits to homepages of authors known to have published valuation studies of recreational fishing;
- searches of web sites of agricultural and resource economics departments at several colleges and universities; and
- searches of web sites of organizations and agencies known to publish environmental and resource economics valuation research [e.g., Resources for the Future (RFF), National Center for Environmental Economics (NCEE), National Oceanic and Atmospheric Administration (NOAA), Library of Congress' Congressional Research Service].

---

[1] Meta-analysis is "the statistical analysis of a large collection of results for individual studies for the purposes of integrating the findings" (Glass, 1976).

From this review, EPA identified approximately 450 journal articles, academic working papers, reports, books, and dissertations that were potentially relevant for this analysis. Forty-eight of these studies were included in the data set for the recreational meta-analysis because they met the criteria listed below:

- **Specific amenity valued:** Selected studies were limited to those that estimated WTP that recreational anglers place on catching an additional fish or provided sufficient information for EPA to calculate such a value;
- **Location:** Selected studies were limited to those that surveyed U.S. or Canadian populations; and
- **Research methods:** Selected studies were limited to those that applied primary research methods supported by journal literature.

The Agency utilized information from each of the studies to compile an extensive data set for use in the meta-analysis. The complete data set is provided in the public record for the proposed rule (see DCN 7-4923 and DCN 7-4924), and includes the following information:

- full study citation;
- study methodology (e.g., research method, survey administration method, question format);
- sample characteristics (e.g., sample size, response rate, income, age, gender);
- study location (e.g., waterbody name, waterbody type, geographic location);
- description of fishing quality (e.g., target species, fishing mode, baseline catch rate, post-change catch rate);
- marginal value per fish, updated to 2004 dollars; and
- methods for obtaining marginal values per fish (i.e., whether marginal value per fish was directly available from the study, marginal value calculation method).

A5-2 Description of Studies

As noted above, EPA selected 48 recreational angling valuation studies that allow estimation of the value of catching an additional fish. These studies were published between 1982 and 2004, and are based on data from surveys conducted between 1977 and 2001. The studies all apply standard, generally accepted valuation methods, such as contingent valuation, travel cost models, and random utility models, to assess marginal value per fish. Studies were excluded if they did not conform to general concepts of economic theory, or if they applied methods not generally accepted in the economic literature.

All selected studies focus on changes in recreational catch rates in the U.S. or Canada. Beyond this general similarity, the studies vary in several respects. Differences include the species targeted by anglers, the magnitude of the change in catch rates, the location of the study, the survey administration method, demographics of the survey sample, and statistical methods employed. The 48 studies include 24 journal articles, 15 reports, five Ph.D. dissertations, three academic or staff papers, and one book. Twenty studies share a primary author with at least one other study. These 20 studies have a combined total of eight individuals as primary authors.

Because multiple estimates of the marginal per-fish value are available from most of the studies, the 48 studies selected for the meta-analysis provide 391 observations for the final data set. Some of the characteristics that allow multiple observations to be derived from a single study include variations in the baseline catch rate, the species being valued, the locations where fish were caught, the fishing method (i.e., boat or shore), and the valuation methodology.

Survey response rates from the studies range from 38% to 99%, and study sample sizes range from 72 to 36,802 responses. Two hundred and ten estimates from 21 studies are based on random utility models, 59 estimates from 11 studies are based on travel cost models, and 122 estimates from 20 studies are based on stated preference methods.[2] EPA calculated the marginal value per fish based on information provided in the study for 93 estimates from 15 studies, and for the remaining estimates the marginal values were provided by the authors.

Table A5-1 lists key study and resource characteristics and indicates the number of observations derived from each study.

From these 48 studies, the Agency compiled a data set for the meta-analysis of marginal values per fish. The following section describes the estimation of this model and its application to the regulatory analysis options for Phase III facilities.

---

[2] The number of studies employing each valuation methodology does not sum to the total number of studies because some studies used different valuation methods, from which multiple observations were derived.

Table A5-1: Select Characteristics of Recreational Angling Valuation Studies Used in the Meta-Analysis[a]

Author and Year	Number of Observations	State(s)	Study Methodology/ Elicitation Format	Marginal Value per Fish[b]
Agnello (1989)	30	FL to NY	Travel cost	Bluefish ($0.72 to $9.49) Flounder ($3.42 to $29.47) Weakfish ($0.05 to $9.96) All three species ($1.19 to $16.24)
Alexander (1995)	8	OR	Nested RUM	Steelhead trout ($3.69 to $23.82)
Berrens et al. (1993)	1	OR	CV (payment card)	Chinook salmon ($4.10)
Besedin et al. (2004b)	12	MI	Non-nested RUM	Bass ($13.51 to $17.60) Perch ($1.84 to $3.03) Walleye/pike ($10.45 to $21.94) Salmon/trout ($21.14 to $24.01) General/no target ($1.62 to $3.43)
Bockstael et al. (1989)	1	MD	Travel cost	*Striped bass* ($2.29)
Boyle et al. (1998)	4	FWS mountain trout, western trout, northeast trout, and northern bass regions	CV (dichotomous choice)	Trout ($0.94 to $4.07) Bass ($4.34)
Breffle et al. (1999)	8	WI		*Yellow perch* ($0.81 to $1.61) *Trout/salmon* ($21.58 to $43.28) *Walleye* ($4.25 to $8.57) *Smallmouth bass* ($14.08 to $28.25)
Cameron and Huppert (1989)	2	CA	CV (payment card)	*Salmon* ($5.98 to $17.23)
Cameron and James (1987a)	1	British Columbia, Canada	CV (dichotomous choice)	Salmon ($2.58)
Cameron and James (1987b)	1	British Columbia, Canada	CV (dichotomous choice)	Salmon ($20.33)
Carson et al. (1990)	3	AK	CV (payment card, conjoint analysis)	Chinook salmon ($16.24 to $47.20)
Dalton et al. (1998)	2	WY	CV (dichotomous choice)	*Trout* ($28.92 to $52.85)
Gautam and Steinbeck (1998)	3	ME, NH, MA, RI, CT	Travel cost, non-nested RUM	Striped bass ($4.30 to $7.22)

Table A5-1: Select Characteristics of Recreational Angling Valuation Studies Used in the Meta-Analysis[a]

Author and Year	Number of Observations	State(s)	Study Methodology/ Elicitation Format	Marginal Value per Fish[b]
Hicks et al. (1999)	44	ME, NH, MA, RI, CT, NY, NJ, DE, MD, VA	Nested RUM	Big game ($5.83 to $8.42) Bottomfish ($2.08 to $3.34) Small game ($3.09 to $4.77) Flatfish ($3.95 to $7.33)
Hicks (2002)	3	NH to VA	CV (conjoint analysis), non-nested RUM	Summer flounder ($2.66 to $4.78)
Huppert (1989)	3	CA	CV (payment card), travel cost	*Chinook salmon and striped bass* ($7.96 to $60.08)
Hushak et al. (1988)	3	OH	Travel cost	*Walleye* ($2.41 to $3.22)
Johnson et al. (1995)	19	CO	CV (iterative bidding, dichotomous choice)	Trout ($0.56 to $3.02)
Johnson (1989)	5	CO	CV (iterative bidding)	Brown and rainbow trout ($0.89 to $1.66) Rainbow trout ($2.65)
Johnson and Adams (1989)	1	OR	CV (multiple methods)	Steelhead trout ($11.46)
Jones and Stokes Associates (1987)	4	AK	Non-nested RUM	*Halibut* ($158.22) *Chinook salmon* ($336.45) *Coho salmon* ($183.65) *Dolly varden* ($23.90)
Kirkley et al. (1999)	10	VA	CV (open-ended)	Bottomfish and croaker ($3.14 to $13.24) Summer flounder ($4.82 to $20.47) Gamefish ($16.86 to $67.43) No target ($1.98 to $8.43)
Lee (1996)	5	WA	CV (conjoint analysis)	Trout ($1.16 to $3.94)
Loomis (1988)	13	OR, WA	Travel cost	Steelhead trout ($42.11 to $187.33) Salmon ($13.60 to $117.41)
Lupi and Hoehn (1998)	3	MI	Nested RUM	Lake trout ($10.40 to $14.29)

Table A5-1: Select Characteristics of Recreational Angling Valuation Studies Used in the Meta-Analysis[a]

Author and Year	Number of Observations	State(s)	Study Methodology/ Elicitation Format	Marginal Value per Fish[b]
Lupi et al. (1997)	10	MI	Nested RUM	*Bass* ($8.78) *Carp* ($1.44) *Coho salmon* ($18.84) *Northern pike* ($2.41) *Rainbow trout* ($10.40 to $16.21) *Chinook salmon* ($4.15 to $13.62) *Lake trout* ($6.79) *Walleye* ($3.76)
McConnell and Strand (1994)	36	FL to NY	CV (dichotomous choice)	*Big game* ($0.67 to $56.09) *Small game* ($11.91 to $31.77) *Flatfish* ($0.38 to $10.79) *Bottomfish* ($0.26 to $4.64)
Milliman et al. (1992)	1	MI	CV (dichotomous choice)	Yellow perch ($0.34)
Morey et al. (1993)	2	ME	Nested RUM	*Atlantic salmon* ($397.45 to $629.94)
Morey et al. (2002)	2	MT	Nested RUM	*Trout* ($11.95 to $203.57)
Morey et al. (1991)	3	OR	Non-nested RUM	*Salmon* ($5.82) *Ocean perch* ($14.12) *Smelt and grunion* ($33.30)
Murdock (2001)	7	WI	Nested RUM	*Panfish* ($10.04) *Walleye* ($23.26) *Smallmouth bass* ($20.01) *Temperate bass* ($4.35) *Northern pike* ($16.12) *Musky* ($166.77) *Trout* ($33.59) *Salmon* ($53.05)
Norton et al. (1983)	4	ME to NC	Travel cost	Striped bass ($3.48 to $32.87)
Olsen et al. (1991)	6	WA, OR	CV (open-ended)	Salmon ($22.56 to $38.49) Steelhead trout ($38.04 to $83.56)
Pendleton and Mendelsohn (1998)	3	ME, NH, VT, NY	Non-nested RUM	Rainbow trout ($24.02) Other trout ($4.44 to $27.18)

Table A5-1: Select Characteristics of Recreational Angling Valuation Studies Used in the Meta-Analysis[a]

Author and Year	Number of Observations	State(s)	Study Methodology/ Elicitation Format	Marginal Value per Fish[b]
Rowe et al. (1985)	24	CA, OR, WA	Non-nested RUM	Coastal pelagics ($3.93 to $4.57) Flatfish ($3.40 to $14.73) Rockfish and bottomfish ($2.70 to $6.98) Salmon ($7.41 to $32.11) Smelt and grunion ($0.31 to $7.61)
Samples and Bishop (1985)	1	MI	Travel cost	Salmon and trout ($19.54)
Schuhmann (1996)	7	NC	Non-nested RUM	*Big game* ($34.73 to $136.83) *Bottomfish* ($14.94) *Drum* ($1.70 to $11.89) *Surface fish* ($13.02 to $26.69)
Schuhmann (1998)	8	MD, NC	Non-nested RUM	*Billfish* ($34.66) *Bottomfish* ($14.92) *Drum* ($11.87) *Surface fish* ($13.01)
Shafer et al. (1993)	1	PA	Travel cost	*Trout* ($1.39)
U.S. EPA (2004a)	31	CA	Non-nested RUM	Big game ($2.21 to $6.65) Bottomfish ($1.42 to $2.84) Flatfish ($3.28 to $11.37) Jacks ($29.97) Salmon ($8.70 to $16.00) Sea bass ($0.37 to $0.75) Small game ($2.32 to $3.18) Striped bass ($4.43 to $8.65) Sturgeon ($63.15) No target/other ($0.47 to $6.87)
U.S. EPA (2004b)	15	NY to VA	Nested RUM	Big game ($21.56) Bluefish ($6.50 to $6.60) Bottomfish ($4.83 to $4.89) Flatfish ($8.79 to $8.99) Other small game ($4.81 to $6.83) Striped bass ($15.95 to $16.00) Weakfish ($14.71 to $15.41) No target ($5.86 to $5.99)

Table A5-1: Select Characteristics of Recreational Angling Valuation Studies Used in the Meta-Analysis[a]

Author and Year	Number of Observations	State(s)	Study Methodology/ Elicitation Format	Marginal Value per Fish[b]
U.S. EPA (2004c)	10	FL, NC, SC, GA	Non-nested RUM	Big game ($38.95) Bottomfish ($5.05 to $9.65) Flatfish ($28.40 to $32.05) Small game ($10.60 to $14.10) Snapper and grouper ($5.56) No target ($7.62 to $20.28)
U.S. EPA (2004d)	13	FL, AL, MS, LA	Non-nested RUM	Big game ($31.33) Bottomfish ($2.27 to $7.43) Flatfish ($9.67 to $17.09) Seatrout ($10.42 to $14.24) Small game ($13.21 to $16.08) Snapper and grouper ($11.59 to $11.79) No target ($5.50 to $6.54)
Vaughan and Russell (1982)	2	USA	Travel cost	Trout ($1.17) Catfish ($0.80)
Whitehead and Haab (1999)	1	NC, SC, GA, FL, AL, MI, LA	Non-nested RUM	Small game ($4.44)
Whitehead and Aiken (2000)	6	USA	CV (dichotomous choice)	Bass ($4.73 to $10.66)
Williams and Bettoli (2003)	8	TN	CV (dichotomous choice)	Trout ($0.64 to $9.69)

[a] Where multiple observations are available from a given study, state, study methodology/elicitation format, and species may take on different values for different observations from that study.

[b] The marginal values per fish presented here represent the highest and lowest values from the study for the specified species or group of species. Italicized values in this column indicate that EPA calculated the marginal value per fish from information in the study. All values are presented in 2004$.

Source: U.S. EPA analysis for this report.

A5-3 Meta-Analysis of Recreational Fishing Studies: Regression Model

EPA estimated a meta-analysis model based on 391 estimates of the value anglers place on catching an additional fish, derived from 48 original studies. The meta-data, model specification, model results, and interpretation of those results are discussed in sections A5-3.1 through A5-3.3.

In a frequently cited work, Glass (1976) characterizes meta-analysis as "the statistical analysis of a large collection of results for individual studies for the purposes of integrating the findings. It provides a rigorous alternative to the casual, narrative discussion of research studies which is commonly used to make some sense of the rapidly expanding research literature" [p. 3; cited in Poe et al. (2001), p. 138]. Meta-analysis is being increasingly explored as a potential means to estimate resource values in cases where original targeted research is impractical, or as a means to reveal systematic components of WTP (Smith and Osborne, 1996; Santos, 1998; Rosenberger and Loomis, 2000a; Poe et al., 2001; Woodward and Wui, 2001; Bateman and Jones, 2003; Johnston et al., 2003). While the literature urges caution in the use and interpretation of benefit transfers for direct policy application (e.g., Desvousges et al., 1998; Poe et al., 2001), such methods are "widely used in the United States by government agencies to facilitate benefit-cost analysis of public policies and projects affecting natural resources" (Bergstrom and De Civita, 1999). Transfers based on meta-analysis are common in both the United States and Canada (Bergstrom and De Civita, 1999).

Depending on the suitability of available data, meta-analysis can provide a superior alternative to the calculation and use of a simple arithmetic mean WTP over the available observations, as it allows estimation of the systematic influence of study methodology, sample characteristics, and natural resource attributes on WTP (Johnston et al., 2003). The primary advantage of a regression-based (statistical) approach is that it accounts for differences among study characteristics that may contribute to changes in WTP, to the extent permitted by available data. An additional advantage is that meta-analysis can reveal systematic factors influencing WTP, allowing assessments of whether, for example, WTP estimates are (on average) sensitive to the baseline resource conditions (Smith and Osborne, 1996).

A5-3.1 Meta-Data

Meta-analysis is largely an empirical, data-driven process, but one in which variable and model selection is guided by theory. Given a reliance on information available from the underlying studies that comprise the meta-data, meta-analysis models most often represent a middle ground between model specifications that would be most theoretically appropriate and those specifications that are possible given available data. Smith and Osborne (1996), Rosenberger and Loomis (2000a), Poe et al. (2001), Bateman and Jones (2003), Dalhuisen et al. (2003), and others provide insight into the mechanics of specifying and estimating meta-equations in resource economics applications.

To guide development of variable specifications, EPA relied upon a set of general principles. These principles are designed to prevent excessive data manipulations and other factors that may lead to misleading model results. The general principles include, all else being equal:

- models should attempt to capture elements of scale of resource changes;
- models should focus on distinguishing marginal values associated with different types of species in different regions, particularly where relevant to the policy question at hand;
- in the absence of overriding theoretical considerations, continuous variables are generally preferred to discrete variables derived from underlying continuous distributions; and
- where possible, exogenous constraints should be avoided in favor of "letting the data speak for themselves."

Based on these criteria, EPA selected a set of variables believed to have a potential influence on the estimated WTP per additional fish caught. Variable selection was guided primarily by prior findings in the literature, and constrained by information available from the original studies that comprise the meta-data. The dependent variable chosen for the meta-analysis is the natural logarithm of WTP per fish, as reported in each original study or as calculated by EPA from information provided by the studies. EPA chose to use the natural log of the dependent variable instead of the linear form, based on (1) data fit, (2) the intuitive nature of results, and (3) the common use of this functional form in the meta-analysis literature (e.g., Smith and Osborne, 1996; Santos, 1998). Section A5-3.2 discusses this decision in greater detail. Per fish values were adjusted to 2004$ based on the relative change in the consumer price index (CPI) from the study year to 2004. The real value per fish over the sample ranged from 4.9 cents to $629.94, with a mean value of $17.29 and a median value of $5.99.

The independent variables included in the meta-analysis characterize the species being valued, study location, baseline catch rate, elicitation and survey methods, demographics of survey respondents, and other specifics of each study. All independent variables are linear. For ease of exposition, these variables are categorized into those characterizing (1) study methodology, (2) sample characteristics, (3) species targeted, and (4) angling quality. Variables included in each category are summarized below.

Study methodology variables characterize such features as:

- the valuation method (e.g., stated preference, travel cost, or random utility model);
- the year in which a study was conducted;
- the survey administration method; and
- reported survey response rates.

Sample characteristics variables characterize such features as:

- the average income of respondents;
- the demographic composition of respondents; and
- the number of fishing trips taken each year by respondents.

Species targeted variables characterize such features as:

- the species targeted by anglers; and
- the geographic region in which the species was targeted.

Angling quality variables characterize such features as:

- the baseline catch rate; and
- the fishing mode (e.g., shore or boat).

Although the interpretation and calculation of most variables is relatively straightforward, a few variables require additional explanation. In particular, the calculation of the dependent variable requires more explanation.[3] The majority of studies provide estimates of WTP per fish, but some studies do not provide estimates of marginal value. In these cases, EPA calculated WTP per fish in one of two ways. The Agency's preferred approach was to use the regression coefficients from the equation presented in the study to calculate the marginal value per fish. For example, a simple linear travel cost model might express the number of trips (*Trips*) taken by a respondent as a function of travel cost (*TC*), the catch rate (*CR*), and whether or not the respondent owns a boat (*B*):

$$Trips = \alpha + \beta TC + \chi CR + \delta B \qquad \text{(Equation 1)}$$

---

[3] All calculations used by EPA to estimate marginal values are documented in DCN 7-4922.

The marginal value per fish is then calculated as follows:

$$\frac{\partial TC}{\partial CR} = \frac{\chi}{\beta} \qquad \text{(Equation 2)}$$

In the case of RUM studies, the deterministic part of the utility function (V) is in general expressed as a function of travel cost (TC), historic catch rates for various fish species (CR), and a vector of other site attributes (X):

$$V(j) = f(TC_j, CR_{j,s}, X_j) \qquad \text{(Equation 3)}$$

where:

V (j) = the expected utility of fishing at site j
TC_j = travel cost to site j
CR (j,s) = historic catch rate for species s at site j
X_j = attributes of site j

Angler willingness-to-pay for catching an additional fish can be calculated as a ratio of the first derivative of the utility function with respect to the travel cost and catch rate variables. This is interpreted as the change in travel cost (TC_j) that is just sufficient to return a representative angler to a baseline level of utility, subsequent to a one-fish increase in catch rate that results in an increase in utility above the baseline. Formally, marginal WTP per fish may be expressed as:

$$WTP_{fish} = -\frac{\partial V(\cdot) / \partial CR}{\partial V(\cdot) / \partial TC} \qquad \text{(Equation 4)}$$

where the numerator and denominator of (4) are directly revealed by statistical model coefficients. Equation 4 expresses the rate at which anglers are willing to exchange a unit increase in catch rates for a unit increase in the costs of travel.

In cases where EPA was not able to calculate marginal willingness-to-pay per fish from the regression coefficients due to insufficient information, the Agency used linear extrapolation to approximate marginal values. In most cases, this involved calculating average WTP per fish for some specified increase in catch rates. For example, if a study reports that the average respondent is willing to pay ten dollars per trip to catch an additional two fish per trip, then EPA calculated average marginal WTP per fish to be ten dollars divided by two fish, or five dollars per fish.

Another set of variables that requires explanation is the variables that characterize the fish species targeted by anglers. The original studies value a large variety of species. To reduce the number of species variables to a manageable number, and to reduce the number of times in which a species-specific dummy variable distinguishes only a single study, EPA assigned each species to an aggregate species group. These assignments were based on the angling, biological, and regional characteristics of each species. The groups include four saltwater species groups (big game, small game, flatfish, and other saltwater fish), two anadromous species groups (salmon and steelhead trout), and five freshwater species groups (panfish, bass, musky, walleye/pike, and trout).[4] The "other saltwater" group includes bottomfish species, species caught by anglers not targeting any particular species, and species that did not clearly fit in one of the other groups. The panfish group includes freshwater species such as

---

[4] The small game group includes some anadromous species, such as striped bass, that spawn in tidal rivers.

yellow perch, catfish, sunfish, and other warmwater species. Some species groups were further subdivided on the basis of regional differences. Table A5-2 shows the species assigned to each aggregate species group.

Table A5-2: Aggregate Species Groups

Aggregate Group	Number of Observations	Species Included[a]
Big game	30	Billfish family, dogfish, rays, sharks, skates, sturgeon, swordfish, tarpon family, tuna, other big game
Small game	74	Barracuda, bluefish, bonito, cobia, dolly varden, dolphinfish, jacks, mackerel, red drum, seatrout, striped bass, weakfish, other small game
Flatfish	46	Halibut, sanddab, summer flounder, winter flounder, other flatfish
Other saltwater	89	Banded drum, black drum, chubby, cod family, cow cod, croaker, grouper, grunion, grunt, high-hat, kingfish, lingcod, other drum, perch, porgy, rockfish, sablefish, sand drum, sculpin, sea bass, smelt, snapper, spot, spotted drum, star drum, white sea bass, wreckfish, other bottom species, other coastal pelagics, “no target” saltwater species
Salmon	44	Atlantic salmon, chinook salmon, coho salmon, other salmon
Steelhead	16	Steelhead trout, rainbow trout (in Great Lakes only)[b]
Muskellunge	1	Muskellunge
Walleye/pike	12	Northern pike, walleye
Bass	14	Largemouth bass, smallmouth bass
Panfish	11	Catfish, carp, yellow perch, other panfish, “general” and “no target” freshwater species
Trout	54	Brown trout, lake trout, rainbow trout, other trout

[a] Some studies evaluated WTP for groups of species that did not fit cleanly into one of the aggregate species groups established by EPA. In those cases, the groups of species from the study were assigned to the aggregate species group with which they shared the most species.

[b] Rainbow trout in the Great Lakes were classified as steelhead trout because they share similar physical characteristics and life cycles with true anadromous steelhead. Although they have different common names, rainbow trout and steelhead both belong to the species *Oncorhynchus mykiss.*

Source: U.S. EPA analysis for this report.

The final set of variables that require additional explanation are the catch rate variables. In general, studies express catch rates in fish per hour, fish per day, fish per trip, or fish per year. Rather than include four separate catch rate variables, EPA combined per hour, per day, and per trip catch rates in a normalized variable called *cr_nonyear*. This variable expresses catch rates in per day units. Because most of the studies focused on single-day trips, EPA included per trip catch rates in this variable without normalization.[5] Per hour catch rates were converted to per day catch rates by multiplying by the number of hours fished per day, as provided in the study. In cases where the study does not provide information on fishing day length, EPA assumed that the average fishing day lasts four hours, which is consistent with the literature where hours are reported. EPA included per year catch rates in a separate variable, *cr_year*.

---

[5] Although some studies included both multiple and single day trips the average angling trip length was often not provided. However, the majority of recreational angling trips are single-day trips. According to the 2001 National Survey of Hunting, Fishing, and Wildlife-Associated Recreation (U.S. DOI and U.S. DOC, 2002), the average angling trip length was 1.27 days.

Variables incorporated in the final model are listed and described in Table A5-3.

Table A5-3: Variables and Descriptive Statistics for the Regression Model

Variable[a]	Description	Units (Range)	Mean (Std. Dev.)
log_WTP	Natural log of the marginal value per fish.	Natural log of dollars (-3.0260 to 6.4180)	1.8419 (1.3165)
SP_conjoint	Binary (dummy) variable indicating that the study used conjoint or choice-experiment stated preference methodology.	Binary variable (0 to 1)	0.0435 (0.2042)
SP_dichot	Binary (dummy) variable indicating that the study used stated preference methodology with a dichotomous choice elicitation format.	Binary variable (0 to 1)	0.1739 (0.3795)
TC_individual	Binary (dummy) variable indicating that the study used a travel cost model based on the number of trips taken by individual respondents to recreational sites.	Binary variable (0 to 1)	0.1074 (0.3100)
TC_zonal	Binary (dummy) variable indicating that the study used a zonal travel cost model based on the aggregate number of trips taken to recreational sites by visitors who live within specified distance ranges.	Binary variable (0 to 1)	0.0409 (0.1984)
RUM_nest	Binary (dummy) variable indicating that the study used a nested random utility model.	Binary variable (0 to 1)	0.2353 (0.4247)
RUM_nonnest	Binary (dummy) variable indicating that the study used a non-nested random utility model.	Binary variable (0 to 1)	0.3043 (0.4607)
SP_year	If the study used stated preference methodology, this variable represents the year in which the study was conducted, converted to an index by subtracting 1976; otherwise, this variable is set to zero.	Year index (0 to 25)	4.6036 (7.3592)
TC_year	If the study used travel cost methodology, this variable represents the year in which the study was conducted, converted to an index by subtracting 1976; otherwise, this variable is set to zero.	Year index (0 to 18)	0.7315 (2.1914)
RUM_year	If the study used RUM methodology, this variable represents the year in which the study was conducted, converted to an index by subtracting 1976; otherwise, this variable is set to zero.	Year index (0 to 25)	9.3734 (9.7162)
sp_mail	Binary (dummy) variable indicating that the study was a stated preference study administered by mail.	Binary variable (0 to 1)	0.0512 (0.2206)
sp_phone	Binary (dummy) variable indicating that the study was a stated preference study administered by phone.	Binary variable (0 to 1)	0.1304 (0.3372)
high_resp_rate	Binary (dummy) variable indicating that the sample response rate was greater than 50%.	Binary variable (0 to 1)	0.3581 (0.4800)
inc_thou	Average household income of survey respondents in thousands of dollars. If the study does not list income values, *inc_thou* was imputed from Census data.	1,000s of June 2003$ (21.990 to 70.610)	46.7008 (10.2017)
age42_down	Binary (dummy) variable indicating that the mean age of sample respondents was less than 43. If the mean sample age was greater than or equal to 43, or was not reported, this variable was set equal to zero.	Binary variable (0 to 1)	0.0972 (0.2966)

Table A5-3: Variables and Descriptive Statistics for the Regression Model

Variable[a]	Description	Units (Range)	Mean (Std. Dev.)
age43_up	Binary (dummy) variable indicating that the mean age of sample respondents was 43 or greater. If the mean sample age was less than 43, or was not reported, this variable was set equal to zero.	Binary variable (0 to 1)	0.2711 (0.4451)
trips19_down	Binary (dummy) variable indicating that the mean number of fishing trips taken each year by sample respondents was less than 20. If the mean number of trips was not reported, this variable was set equal to zero.	Binary variable (0 to 1)	0.1100 (0.3133)
trips20_up	Binary (dummy) variable indicating that the mean number of fishing trips taken each year by sample respondents was 20 or greater. If the mean number of trips was not reported, this variable was set equal to zero.	Binary variable (0 to 1)	0.3350 (0.4726)
nonlocal [c]	Binary (dummy) variable indicating that no respondents in the sample were local residents.	Binary variable (0 to 1)	0.0051 (0.0714)
big_game_pac[c]	Binary (dummy) variable indicating that the target species was big game in the California or Pacific Northwest regions.	Binary variable (0 to 1)	0.0077 (0.0874)
big_game_natl	Binary (dummy) variable indicating that the target species was big game in the North Atlantic or Mid-Atlantic regions.	Binary variable (0 to 1)	0.0486 (0.2153)
big_game_satl	Binary (dummy) variable indicating that the target species was big game in the South Atlantic or Gulf of Mexico regions.	Binary variable (0 to 1)	0.0205 (0.1418)
small_game_pac	Binary (dummy) variable indicating that the target species was small game in the California or Pacific Northwest regions.	Binary variable (0 to 1)	0.0281 (0.1656)
small_game_atl	Binary (dummy) variable indicating that the target species was small game in the North Atlantic, Mid-Atlantic, South Atlantic, or Gulf of Mexico regions.	Binary variable (0 to 1)	0.1611 (0.3681)
flatfish_pac	Binary (dummy) variable indicating that the target species was flatfish in the California or Pacific Northwest regions.	Binary variable (0 to 1)	0.0179 (0.1328)
flatfish_atl	Binary (dummy) variable indicating that the target species was flatfish in the North Atlantic, Mid-Atlantic, South Atlantic, or Gulf of Mexico regions.	Binary variable (0 to 1)	0.0997 (0.3000)
other_sw	Binary (dummy) variable indicating that the target species was bottom fish or other saltwater species.	Binary variable (0 to 1)	0.2276 (0.4198)
musky [c]	Binary (dummy) variable indicating that the target species was muskellunge.	Binary variable (0 to 1)	0.0026 (0.0506)
pike_walleye	Binary (dummy) variable indicating that the target species was northern pike or walleye.	Binary variable (0 to 1)	0.0307 (0.1727)
bass_fw	Binary (dummy) variable indicating that the target species was largemouth bass or smallmouth bass.	Binary variable (0 to 1)	0.0358 (0.1860)
trout_GL	Binary (dummy) variable indicating that the target species was trout in the Great Lakes region.	Binary variable (0 to 1)	0.0128 (0.1125)
trout_nonGL	Binary (dummy) variable indicating that the target species was trout in states outside the Great Lakes region.	Binary variable (0 to 1)	0.1253 (0.3315)

Table A5-3: Variables and Descriptive Statistics for the Regression Model

Variable[a]	Description	Units (Range)	Mean (Std. Dev.)
salmon_pacific	Binary (dummy) variable indicating that the target species was salmon on the Pacific Coast.	Binary variable (0 to 1)	0.0844 (0.2783)
salmon_atl_Morey[c]	Binary (dummy) variable indicating that the target species was salmon on the Atlantic Coast.	Binary variable (0 to 1)	0.0051 (0.0714)
salmon_GL	Binary (dummy) variable indicating that the target species was salmon in the Great Lakes.	Binary variable (0 to 1)	0.0230 (0.1502)
steelhead_pac	Binary (dummy) variable indicating that the target species was steelhead on the Pacific Coast.	Binary variable (0 to 1)	0.0358 (0.1860)
steelhead_GL[c]	Binary (dummy) variable indicating that the target species was steelhead in the Great Lakes.	Binary variable (0 to 1)	0.0051 (0.0714)
cr_nonyear	For studies that present catch rate on a per hour, per day, or per trip basis, this variable represents the baseline catch rate for the target species, expressed in fish per day or fish per trip; otherwise this variable is set to zero. See text for calculation details.	Fish per day (0 to 14.0000)	2.1038[b] (2.0403)
cr_year	For studies that present catch rate on a per year basis, this variable represents the baseline catch rate for the target species, expressed in fish per year; otherwise this variable is set to zero.	Fish per year (0 to 67.3800)	41.2277[b] (24.7833)
catch_year	Binary (dummy) variable indicating that the study expressed catch rates on a per year basis.	Binary variables (0 to 1)	0.0716 (0.2582)
spec_cr	Binary (dummy) variable indicating that the study presents information on the baseline catch rate.	Binary variable (0 to 1)	0.8440 (0.3633)
shore	Binary (dummy) variable indicating that all respondents in the sample fished from shore.	Binary variable (0 to 1)	0.1458 (0.3633)

[a] The default variable values are:

- A zero value for all of the study methodology variables (*SP_conjoint*, *SP_dichot*, *TC_individual*, *TC_zonal*, *RUM_nested*, and *RUM_nonnested*) indicates that the study used a stated preference methodology with an open-ended, iterative bidding, or payment card elicitation format.
- A zero value for *sp_mail* or *sp_phone* indicates that the study was a stated preference study administered in person.
- A zero value for *nonlocal* indicates that the survey included local anglers or a mix of local and nonlocal anglers.
- A zero value for all of the species variables indicates that the target species was panfish caught nationwide.
- A zero value for *shore* indicates that survey respondents fished from boats or from both the shore and from boats.

[b] These values represent mean values and standard deviations *only* for those observations in which the variable value was specified. Zero values are suppressed for the purposes of calculating the mean and standard deviation.

[c] An important qualification applies to the variables *nonlocal*, *salmon_atlantic_Morey*, *big_game_pac*, *steelhead_GL*, and *musky*. These variables were judged to represent unique categories of angler and species characteristics, and as such were included in the model. However, none of these variables represent more than three observations in the meta-data. Hence, results associated with these variables should be interpreted with caution, given that these variables might also capture study-level effects.

Source: U.S. EPA analysis for this report.

A5-3.2 Model and Results

a. Model

Past meta-analyses have incorporated a range of different statistical methods, with none universally accepted as superior (e.g., Santos, 1998; Poole and Greenland, 1999; Poe et al., 2001; Bateman and Jones, 2003). Nonetheless, there is general consensus that certain statistical issues should be addressed during model development. For example, many researchers agree that models must somehow address potential correlation among observations provided by like authors or studies and the related potential for heteroskedasticity (Rosenberger and Loomis, 2000b; Bateman and Jones, 2003; Johnston et al., 2003). This meta-analysis model is estimated following standard methods illustrated in the most recent literature, recognizing that there are some areas in which the literature provides mixed guidance (e.g., the use of weighting).

EPA followed recent work by Bateman and Jones (2003) in applying a multilevel model specification to the meta-data to address potential correlation among observations gathered from single studies. Multilevel (or hierarchical) models may be estimated as either random-effects or random-coefficients models, and are described in detail elsewhere (Goldstein, 1995; Singer, 1998). The fundamental distinction between these models and classical linear models is the two-part modeling of the equation error to account for hierarchical data. Here, the meta-data are comprised of multiple observations per valuation survey (i.e., all observations from studies that were based on a common survey), and there is a corresponding possibility of correlated errors among observations that share a common survey.[6]

The common approach to modeling such potential correlation is to divide the residual variance of estimates into two parts: a random error that is independently and identically distributed (iid) across all observations, and a random effect that represents systematic variation related to each survey. The model is estimated as a two-level hierarchy, with level one corresponding to marginal value per fish estimates (individual observations), and level two corresponding to individual surveys. The random effect may be interpreted as a deviation from the mean equation intercept associated with individual surveys (Bateman and Jones, 2003). The model is estimated using a maximum likelihood estimator (MLE), based on the assumption that random effects are distributed multivariate normal. Following the arguments of Bateman and Jones (2003), observations are unweighted. Also following prior work (e.g., Smith and Osborne, 1996; Poe et al., 2001), covariances are obtained using the Huber-White covariance estimator. As described by Smith and Osborne (1996, p. 293), "this approach treats each study as the equivalent of a sample cluster with the potential for heteroskedasticity . . . across clusters" (Smith and Osborne, 1996).

Random effects models such as the multilevel model applied here are increasingly becoming standard in resource economics applications, and are estimable using a variety of readily available software packages. For comparison, models were also estimated using both ordinary least squares (OLS) and weighted least squares (WLS) with robust variance estimation and multilevel models with standard (non-robust) variance estimation. Although the OLS R^2 value was somewhat better than the illustrated model, the significance of the individual variable coefficients was highest in the illustrated model.

As noted in section A5-3.1, the dependent variable in the regression is the log of WTP per fish, and the independent variables are all linear, resulting in a semi-log functional form. This functional form has advantages because of: (1) its fit to the data, (2) the intuitive results provided by the functional form, and (3) the common use of this functional form in the meta-analysis literature (e.g., Smith and Osborne, 1996; Santos, 1998). While linear forms are also common in the literature (Rosenberger and Loomis, 2000a,b; Poe et al., 2001; Bateman and Jones, 2003), specifications requiring more intensive data transformations (e.g., Box-Cox, log-log) are less common. Given questions about *a priori* restrictions on the functional form, final decisions regarding functional forms were made based on a combination of general principles and empirical performance. The semi-log model was chosen

---

[6] EPA chose to group observations by valuation survey rather than by study or author because in a number of cases, studies based on the same survey produce similar results, even if written by different authors.

over the linear model based on the ability of the semi-log form to capture curvature in the valuation function and its improved fit to the data. It also allows independent variables to influence WTP (after transformation from its natural log) in a multiplicative rather than additive manner.

❖ A note on model specification

Following standard econometric practice, the final model is specified based on guidance from theory and prior literature. For example, Arrow et al. (1993) make a fundamental distinction between discrete choice and open-ended payment mechanisms (where open-ended include iterative bidding, payment cards, etc.). Hence, this is the distinction made in the final model (i.e., including the variables *SP_conjoint* and *SP_dichot*). Similarly, other methodology variables in the model were chosen based on theoretical considerations and prior findings in the literature (e.g., nested RUM vs. non-nested RUM; mail surveys vs. phone vs. in-person surveys).

As is common in meta-analysis, some variables were excluded from the model because sufficient data were incomplete or missing from most studies in the meta-data. For example, a variable characterizing the average number of years respondents had been fishing was excluded because too few observations were available. Some other variables were also excluded because of a clear lack of statistical significance in all estimated models. For example, if there was no overriding theoretical or other rationale for retaining the variable in the model, and the variable was clearly insignificant, EPA excluded the variable from the model. For example, variables representing gender, survey size, and estimate size were dropped because they added no significant explanatory power to the model. However, certain variables were retained in the model for theoretical reasons, even if significance levels were low. Such specification of meta-analysis models using a combination of theoretical guidance and empirical considerations is standard in modeling efforts.

b. Results

Table A5-4 presents the results of the model.

Table A5-4: Estimated Multilevel Model Results: Marginal Value per Fish

Variable	Parameter Estimate	Standard Error	t Value	Prob>|t|
Intercept	-1.4568	1.0284	-1.42	0.1663
SP_conjoint	-1.1672	0.3973	-2.94	0.0035
SP_dichot	-0.9958	0.2455	-4.06	<0.0001
TC_individual	1.1091	0.5960	1.86	0.0637
TC_zonal	2.0480	0.6444	3.18	0.0016
RUM_nest	1.3324	0.6377	2.09	0.0375
RUM_nonnest	1.7892	0.6131	2.92	0.0038
sp_year	0.08754	0.02588	3.38	0.0008
tc_year	-0.03965	0.03187	-1.24	0.2144
RUM_year	-0.00291	0.01948	-0.15	0.8814
sp_mail	0.5440	0.4608	1.18	0.2386
sp_phone	1.0859	0.4098	2.65	0.0084
high_resp_rate	-0.6539	0.2779	-2.35	0.0192
inc_thou	0.003872	0.01398	0.28	0.7820
age42_down	0.9206	0.2612	3.52	0.0005
age43_up	1.2221	0.2369	5.16	<0.0001
trips19_down	0.8392	0.2230	3.76	0.0002
trips20_up	-1.0112	0.4381	-2.31	0.0216
nonlocal	3.2355	0.4666	6.93	<0.0001
big_game_pac	2.2530	0.4048	5.57	<0.0001
big_game_natl	1.5323	0.4544	3.37	0.0008
big_game_satl	2.3821	0.5356	4.45	<0.0001
small_game_pac	1.6227	0.3488	4.65	<0.0001
small_game_atl	1.4099	0.7094	1.99	0.0477
flatfish_pac	1.8909	0.4826	3.92	0.0001
flatfish_atl	1.3797	0.3373	4.09	<0.0001
other_sw	0.7339	0.3902	1.88	0.0609
musky	3.8671	0.3507	11.03	<0.0001
pike_walleye	1.0412	0.3469	3.00	0.0029
bass_fw	1.7780	0.4301	4.13	<0.0001
trout_GL	1.8723	0.2620	7.15	<0.0001
trout_nonGL	0.8632	0.3034	2.84	0.0047
salmon_pacific	2.3570	0.4205	5.60	<0.0001
salmon_atl_morey	5.2689	0.4100	12.85	<0.0001
salmon_GL	2.2135	0.2722	8.13	<0.0001
steelhead_pac	2.1904	0.5635	3.89	0.0001
steelhead_GL	2.3393	0.2198	10.64	<0.0001
cr_nonyear	-0.08135	0.06810	-1.19	0.2331
cr_year	-0.05208	0.01451	-3.59	0.0004

Table A5-4: Estimated Multilevel Model Results: Marginal Value per Fish

Variable	Parameter Estimate	Standard Error	t Value	Prob>|t|
catch_year	1.2693	0.4888	2.60	0.0098
spec_cr	0.6862	0.2323	2.95	0.0034
shore	-0.1129	0.1299	-0.87	0.3854
	Full Model	*Random Effects*		
-2 log likelihood	946.0	1227.0		
Chi-square for test of random effects	0.0000	281.0		
Prob>Chi-square	1.000	<0.0001		
Covariance factors:				
Study level (σ_u)	$1.25 * 10^{-19}$			
Residual (σ_e)	0.6581			
Source: U.S. EPA analysis for this report.				

A5-3.3 Interpretation of Regression Analysis Results

The analysis finds both statistically significant and intuitive patterns that influence marginal WTP for catching an additional fish. In general, the statistical fit of the equation is good; there is a strong systematic element to WTP variation that allows forecasting of WTP based on species and study characteristics. The model as a whole is statistically significant at $p<0.0005$. Of the 41 independent variables in the model (not including the intercept), 35 are statistically significant at the 10% level, and most of those are statistically significant at the 1% level. Signs of significant parameter estimates generally correspond with intuition, where prior expectations exist. As shown in Table A5-4, the random effects are not statistically significant, indicating that study level heterogeneity does not have a statistically significant impact on the model.

a. Source study methodology effects

Twelve variables characterize source study methodology. Many of these variables have coefficients that are consistent with prior expectations of sign and relative magnitude. Others have results that are less intuitively clear. For example, interpretation of the parameter estimates of the year variables is not straightforward. Model results show that the *tc_year* and *RUM_year* both have negative but insignificant parameter estimates. These insignificant parameter estimates may indicate that study year has no significant impact on estimated WTP. Alternatively, it may result from a lack of variability in the meta-data for certain variables (e.g., *tc_year*) or from correlation with other model variables. Of slightly more concern is the parameter estimate for *sp_year*, which is positive and significant. This finding is consistent with the hypothesis that real WTP increases over time due to changes in angler experiences, preferences, or purchasing power (Rosenberger and Loomis, 2000a). However, it contradicts the expectation that advances in stated preference survey design over time have led to more conservative WTP estimates (Arrow et al., 1993; Johnston et al., 2003).

Of the revealed preference methodology variables, *TC_individual* has the smallest coefficient, followed by *RUM_nest*, *RUM_nonnest*, and *TC_zonal*. Although theory does not provide unambiguous guidance regarding expected magnitude of these variables, nested RUM models account for substitution effects across different fish species. Hence, one might expect these models to produce lower WTP values per fish compared to the non-nested RUM models and travel cost models. Given that random utility models explicitly take into account the presence of substitute sites, they might also be expected to produce lower WTP estimates for accessing a given recreational site compared to the travel cost models. However, there is no clear theoretical reason to expect non-nested RUM models to produce lower WTP per marginal fish compared to individual (non-RUM) travel cost models.

The stated preference dummy variables (*SP_conjoint*, *SP_dichot*, and the default value, *SP_other*) have much lower coefficients than the travel cost and random utility model variables. This finding is consistent with past research by Cameron (1992) and others, who demonstrate that stated preference methods can produce lower estimates of direct use values for the same quality change than revealed preference methods. However, interpretation of the methodology variables associated with the stated preference approaches is confounded by the large positive coefficient on *sp_year*, which indicates that among more recent studies, revealed preference methods may produce higher estimates of WTP per additional fish.

Of the remaining three methodology variables, two are significant. The variable *sp_phone* has a significantly positive coefficient, indicating that phone interview methods tend to yield higher WTP values than in-person interview methods. The variable *sp_mail* was retained in the meta-analysis for theoretical reasons, despite its lack of statistical significance. The parameter estimate of the binary variable *high_response_rate* is negative and significant ($p<0.05$), a finding consistent with prior expectations.

b. Sample characteristics effects

Six variables characterize demographic and economic attributes. Five of the associated parameter estimates are statistically significant at $p<0.05$, and most have expected signs.

Model results show that respondents with higher incomes (*inc_thou*) are willing to pay more to catch an additional fish per trip — an expected result. The parameter estimate on *age42_down* is less than the parameter estimate on *age43_up*, suggesting that older anglers may be willing to pay more to catch an additional fish. Insofar as *age* is correlated with income, the difference between these variables may be capturing the effects of increased angler income. However, this result is not entirely intuitive, since older anglers may have more experience and are therefore likely to have better success rates. Thus, they might not be willing to pay as much to catch additional fish, due to diminishing marginal WTP per fish caught.

The parameter estimate for *trips19_down* is much larger than the parameter estimate for *trips20_up*, indicating that anglers who take more fishing trips per year (and who presumably catch more fish during the fishing season) have lower marginal values per fish than anglers who take fewer trips per year. This is not surprising, since catching an additional fish during a single trip increases total seasonal catch for avid anglers by a smaller percentage than for anglers who fish less often. Moreover, those taking a greater number of trips, and presumably catching more fish, might be expected to have a somewhat diminished WTP for an additional fish, again based on the concept of diminishing marginal utility.

The parameter estimate for the *nonlocal* variable is positive and significant ($p<0.0001$) indicating that anglers who travel out of state to fish are willing to pay much more to catch additional fish than local residents. However, this effect should be interpreted in the context of the underlying data. This variable is based on only two observations and reflects values of anglers who travel long distances (e.g., visit Alaska) to their fishing destinations.[7] Hence, EPA suggests that results for this variable may not be readily generalizable.

c. Species targeted effects

The model includes 18 binary variables that characterize the target species and region in which the species was targeted. All but one of these variables have coefficients that are significant at $p<0.05$. The variables can be divided into three general groups: marine species, freshwater species, and salmonoids. In general, the sign and magnitude of the coefficients of most of the variables are consistent with prior expectations regarding both the relative worth of different species and the relative worth of individual species in different geographic regions. However, unlike other variables, these expectations are based on existing literature, prior empirical results, and anecdotal evidence, rather than economic theory.

---

[7] In alternative model specifications, EPA was not able to find a statistically significant difference between the variables *local* (representing survey samples that included only local residents) and *local_nonlocal* (representing survey samples that included a mix of local and nonlocal residents).

Of the marine species variables, *big_game_pac* and *big_game_satl* have the largest magnitude. *Big_game_natl* has a somewhat lower coefficient, which is likely due to a somewhat different species composition in the big game category in the North Atlantic and Mid-Atlantic regions. *Small_game_atl* has a slightly smaller coefficient than *small_game_pac*, and *flatfish_atl* has a lower coefficient than *flatfish_pac*, but these differences are not statistically significant. As expected, the *other_sw* variable, which includes bottomfish, smelt, grunion, and other miscellaneous saltwater species, has a relatively small coefficient compared to the other marine species.

Results for the freshwater variables also meet prior expectations. Among warmwater species, *musky* has the highest coefficient, followed by *trout_GL* and *bass_fw*. These results are expected, given that muskellunge are relatively rare and generally grow much larger than other fish in the pike family (*pike_walleye*), and trout caught in the Great Lakes are often much larger than trout caught in smaller rivers and lakes (*trout_nonGL*). The default value for the regression is *panfish*, which includes species such as catfish, and perch. Regression results indicate that the value of catching an additional fish of these species is significantly lower than the other species.

The coefficients of the salmon and steelhead variables are fairly large. These findings are consistent with the popularity of salmonoids as game fish. *Salmon_atlantic_Morey* has a very large coefficient, but this variable is based on observations from only one study — hence results for this variable should be interpreted accordingly.[8] *Salmon_GL* has a lower coefficient than *salmon_pacific*, which is consistent with the larger size of Pacific salmon. *Steelhead_GL* has a slightly higher coefficient than either *steelhead_pac* or *salmon_GL*.

d. Angling characteristics

The angling characteristics variables include two catch rate variables (*cr_nonyear* and *cr_year*), two dummy variable indicating whether catch rates were specified (*spec_cr*) and what units were used (*catch_year*), and a fishing mode variable (*shore*). The negative parameter estimates on both *cr_nonyear* and *cr_year* indicate that anglers' WTP for catching an additional fish per trip decreases as the number of fish already caught increases.[9] This result is consistent with both economic theory and prior expectations. The parameter estimate on the *shore* variable is negative but insignificant.

e. Model limitations

Although the meta-analysis results presented in the previous section indicate that the model's statistical fit is quite good, EPA notes that there are a number of limitations and uncertainties involved in the estimation and results of the model. These limitations stem largely from the quality and quantity of information available from the original studies, and from the statistical methods used to estimate the model.

First of all, regardless of the explanatory power of the meta-analysis regression equation, the model is only as good as the data upon which it is based. EPA believes that WTP per fish estimates from the 24 peer-reviewed journal articles are based on careful, high quality research. The data set also includes estimates from 24 reports, dissertations, academic working papers, and books, which may or may not be subject to the same academic scrutiny and quality standards. Nonetheless, based on EPA's review of these documents, the Agency believes that all of the estimates included in the data set are of reasonable academic quality.

Another limitation of the data is that some demographic and other variables are present for only a subset of the meta-observations. For example, the variables *age* and *trips* have a large number of missing observations, indicating that the original studies do not always provide detailed demographic data. By specifying variables to indicate missing observations (missing observations are indicated by zero values for both *age42_down* and *age43_up*, and for both *trips19_down* and *trips20_up*), EPA was able to control for the missing data. This

---

[8] The study was based on Atlantic salmon fishing in Maine in 1988. Angling for Atlantic salmon is currently illegal in Maine (MaineToday.com, 2003).

[9] Although *cr_nonyear* lacks significance ($p<0.32$), this variable is consistently negative across a variety of model specifications.

specification presumes that a fixed shift in intercept (i.e., using a dummy variable) is sufficient to control for systematic differences associated with the lack of data for specific variables — an unverifiable assumption. Moreover, the significance of these variables would be clearer if more observations were available.

A third limitation of the data, related to variable specification, is the imperfect match between the aggregate species variables specified in the model and the species evaluated in each individual study. Although in most cases the match was good, some studies provided WTP per fish estimates for very broad categories of species, such as “bottomfish (flounder family, cod family, snapper, grouper, jack, grunt, sea bass, porgy, wreckfish)” (Schuhmann, 1998). EPA assigned these estimates to the aggregate species group variable that most closely matched the largest number of species from the list provided in the study, but the Agency acknowledges that this process introduces uncertainty into the analysis.

Another source of uncertainty related to the species groupings is that creating variables for aggregate species groups reduces the precision of the resulting benefit estimates. By aggregating species into categories, EPA was able to improve the fit of the meta-analysis model, but this aggregation also results in a lower level of detail in the values that can be predicted. In particular, the panfish, other saltwater, and big game categories include relatively diverse species.

Model results are also subject to choices regarding functional form and statistical approach, although many of the primary model effects are robust to reasonable changes in functional form and/or statistical methods. The rationale for the specific functional form and model structure chosen is detailed above in section A5-3.2a. In general, meta-analysis may provide a superior alternative to the calculation and use of a simple arithmetic mean, as it allows WTP to be adjusted to account for the characteristics of the transfer site. The model’s ability to adjust WTP appropriately is suggested by the many systematic (statistically significant) patterns revealed by the meta-analysis regression. Nonetheless, the use and interpretation of meta-analysis models for benefit transfer, and the use of benefit transfer in general, are subject to the constraints and concerns expressed elsewhere in the literature (e.g., Desvousges et al., 1998; Poe et al., 2001; Vandenberg et al., 2001).

A5-4 Application of the Meta-Analysis Results to the Analysis of Recreational Benefits of the Section 316(b) Regulatory Analysis Options for Phase III Facilities

The results of the meta-analysis in conjunction with information specific to the resource users and populations of species that will benefit from reduced I&E can be used to estimate the recreational welfare gain associated with the section 316(b) regulatory analysis options for Phase III facilities. This analysis involves the following steps:

- estimating the marginal recreational value per fish for each species affected by each respective analysis option in each region;
- calculating the recreational fishing benefits from eliminating baseline I&E losses, by multiplying the marginal value per fish by the number of recreational fish currently lost to I&E that would otherwise be caught by recreational anglers; and
- calculating the recreational fishing benefits from the regulatory analysis options for Phase III facilities, by multiplying the marginal value per fish by the number of additional fish that would be caught by recreational anglers because of reduced I&E losses of recreational fish.

A5-4.1 Estimating Marginal Value per Fish

EPA used the estimated meta-regression to estimate marginal values per fish for the species affected by I&E at Phase III facilities. To calculate the marginal value per fish for the affected species, EPA chose input values for the independent variables based on the affected species characteristics, study regions, and demographic characteristics of the affected angling populations. The study design variables were selected based on current economic literature. Table A5-5 summarizes the input values for each of the variables in the model.

Table A5-5: Independent Variable Assignments for Regression Equation			
Variable	**Coefficient**	**Assigned Value**	**Explanation**
Intercept	-1.4568	1	The equation intercept was set to one by default.
SP_conjoint	-1.1672	0	Current academic literature suggests that nested RUM models produce the most accurate valuation results, so *RUM_nest* was set to one, and the other study methodology variables were set to zero.
SP_dichot	-0.9958	0	
TC_individual	1.1091	0	
TC_zonal	2.0480	0	
RUM_nest	1.3324	1	
RUM_nonnest	1.7892	0	
sp_year	0.08754	0	Because more recent studies are expected to be more accurate, *RUM_year* was set equal to 24 (equivalent to 2000 minus 1976).
tc_year	-0.03965	0	
RUM_year	-0.00291	24	
sp_mail	0.5440	0	Since *RUM_nest* was the model specified above, *sp_mail* and *sp_phone* were set to zero.
sp_phone	1.0859	0	
high_resp_rate	-0.6539	1	High survey response rates are desirable because they may provide more accurate estimates, so *high_response_rate* was set to one.
inc_thou	0.003872	Varies	*Inc_thou* was set to the median household income for each study region evaluated, based on U.S. Census data.
age42_down	0.9206	0.0972	*Age42_down* and *age43_up* were set to their sample means.
age43_up	1.2221	0.2711	
trips19_down	0.8392	0.1100	*Trips19_down* and *trips20_up* were set to their sample means.
trips20_up	-1.0112	0.3350	
nonlocal	3.2355	0	Because the default (zero) value for the *nonlocal* dummy variable represents a combination of local and nonlocal anglers, *nonlocal* was set to zero.
big_game_pac	2.2530	Varies	Species targeted variables were assigned input values based on characteristics of the species affected by I&E and the study region. In general, the match between the affected species and the variables in the meta-analysis equation was good.
big_game_natl	1.5323	Varies	
big_game_satl	2.3821	Varies	
small_game_pac	1.6227	Varies	
small_game_atl	1.4099	Varies	
flatfish_pac	1.8909	Varies	
flatfish_atl	1.3797	Varies	
other_sw	0.7339	Varies	
musky	3.8671	Varies	
pike_walleye	1.0412	Varies	
bass_fw	1.7780	Varies	
trout_GL	1.8723	Varies	
trout_nonGL	0.8632	Varies	
salmon_pacific	2.3570	Varies	
salmon_atl_morey	5.2689	Varies	
salmon_GL	2.2135	Varies	
steelhead_pac	2.1904	Varies	
steelhead_GL	2.3393	Varies	

Table A5-5: Independent Variable Assignments for Regression Equation

Variable	Coefficient	Assigned Value	Explanation
cr_nonyear	-0.08135	Varies	The variable *cr_nonyear* was assigned species and region-specific values for the coastal and Great Lakes regions based on catch rates data provided by NMFS (2002d, 2003c) and MDNR (2002). For the Inland region, EPA assigned values to the *cr_nonyear* variable based on the average values for each species from the studies. The variable *spec_cr* was set to one. *Cr_year* and *catch_year* were set to zero, since catch per trip and catch per day are more common measures of angling quality.
cr_year	-0.05208	0	
catch_year	1.2693	0	
spec_cr	0.6862	1	
shore	-0.1129	Varies	*Shore* was assigned values based on NMFS (2002d, 2003c) and FWS (U.S. DOI and U.S. DOC, 2002) survey data indicating the average percentage of anglers who fish from shore in each region.

Source: U.S. EPA analysis for this report.

Table A5-6 presents region- and species-specific values for the input variables that vary across regions.

Table A5-6: Region- and Species-Specific Variable Assignments for Regression Equation

		Region						
Variable		**California**	**North Atlantic**	**Mid-Atlantic**	**South Atlantic**	**Gulf of Mexico**	**Great Lakes**	**Inland**
inc_thou		54.385	55.000	51.846	40.730	36.641	44.519	58.240
shore		24.0	24.0	23.1	30.0	25.0	48.0	57.0
Species	**Species Type Dummy Variable**[a]	**Baseline Catch Rate, Expressed in Fish per Day** (*cr_nonyear*)						
Small game[b]	*small_game_atl*, *small_game_pac*	2.7	1.6	1.6	2.2	2.2		2.1
Flatfish[c]	*flatfish_atl*, *flatfish_pac*	1.3	1.0	1.0	1.5			
Other saltwater	*other_sw*	1.7	1.7	1.7	1.7	1.7		
Salmon	*salmon_GL*						0.2	
Walleye/pike	*pike_walleye*						0.8	0.8
Bass	*bass_fw*						0.2	0.2
Panfish[d]				4.7			4.7	4.7
Trout							3.2	3.2
Unidentified		1.7	1.7	1.7	1.7	1.9	1.9	3.8

[a] This column indicates which species type dummy variable was set to one to represent each species.

[b] For small game in the North Atlantic, Mid-Atlantic, South Atlantic, Gulf of Mexico, and Inland regions, *small_game_atl* was set to one. For small game in the California region, *small_game_pac* was set to one.

[c] For flatfish in the North Atlantic, Mid-Atlantic, South Atlantic, Gulf of Mexico, Great Lakes, and Inland regions, *flatfish_atl* was set to one. For flatfish in the California region, *flatfish_pac* was set to one.

[d] To indicate that the target species was panfish, all species type dummy variables were set to zero.

Source: U.S. EPA analysis for this report.

EPA decided not to include the error term when using the regression equation to predict marginal values per fish. Bockstael and Strand (1987) argue that if the source of econometric error in an equation is primarily due to omitted variables, the error term should be included, but if the error is primarily due to random preferences, it should be excluded. Because the error term is positive, the empirical effect of including this term is to increase the predicted marginal values. Therefore, EPA's approach results in more conservative estimates. The Agency also notes that when the error term is excluded, the values predicted by the regression equation are more consistent with those from the underlying studies.

Table A5-7 presents the estimated marginal value per fish for all species that were affected by I&E in each region.

Table A5-7: Marginal Recreational Value per Fish, by Region and Species[a]

Species	California	North Atlantic	Mid-Atlantic	South Atlantic	Gulf of Mexico	Great Lakes	Inland
Small game	$6.11	$5.00	$4.97	$4.82	$4.74		$4.51
Flatfish	$8.22	$5.02	$4.73	$4.73			
Other saltwater	$2.49	$2.51	$2.46	$2.40	$2.34		
Salmon						$11.17	
Walleye/pike						$3.46	$3.45
Bass						$7.21	$7.59
Panfish			$0.89			$1.12	$0.89
Trout						$7.94	$2.38
Unidentified	$2.61	$2.53	$2.73	$2.41	$3.08	$5.24	$1.88

[a] All values are in 2004$.

Source: U.S. EPA analysis for this report.

A5-4.2 Calculating Recreational Benefits

EPA estimated the recreational welfare gain from eliminating current I&E losses and the recreational welfare gain from the regulatory analysis options by combining estimates of the marginal value per fish with estimates of the baseline level of I&E and the reduction in recreational fishing losses from I&E attributable to each analysis option. To calculate the recreational welfare gain from eliminating current I&E losses, EPA multiplied the marginal value per fish by the number of fish that are currently lost due to I&E that would otherwise be caught by recreational anglers. To calculate the recreational welfare gain from each analysis option, EPA multiplied the marginal value per fish by the additional number of fish caught by recreational anglers that would have been impinged or entrained in the absence of the regulation. In these calculations, recreational fish losses are expressed as the number of mature, catchable adults, not as age-1 equivalents so as to not overstate the increase in catch. The results of these calculations are presented in detail in Chapters B4 through H4 of this report.

A5-5 Limitations and Uncertainties

A number of issues are common to all benefit transfers. Benefit transfer involves adapting research conducted for another purpose to address the policy questions at hand. Because benefits analysis of environmental regulations rarely affords sufficient time to develop original stated preference surveys that are specific to the policy effects, benefit transfer is often the only option to inform a policy decision. Specific issues associated with the estimated regression model and the underlying studies are discussed in section A5-3.3. Additional limitations and uncertainties associated with implementation of the meta-analysis approach are addressed below.

A5-5.1 Sensitivity Analysis Based on Krinsky and Robb (1986) Approach

The meta-analysis model presented above can be used to predict mean WTP for catching an additional fish. However, estimates derived from regression models are subject to some degree of error and uncertainty. To better characterize the uncertainty or error bounds around predicted WTP, EPA adapted the statistical procedure described by Krinsky and Robb in their 1986 *Review of Economics and Statistics* paper "Approximating the Statistical Property of Elasticities." The procedure involves sampling from the variance-covariance matrix and means of the estimated coefficients, both of which are standard output from the statistical package used to estimate the meta-model. WTP values are then calculated for each drawing from the variance covariance matrix, and an empirical distribution of WTP values is constructed. By varying the number of drawings, it is possible to generate an empirical distribution with a desired degree of accuracy (Krinsky and Robb, 1986). The lower or upper bound of WTP values can then be identified based on the 5th and 95th percentile of WTP values from the empirical distribution. These bounds may help decision-makers understand the uncertainty associated with the benefit results.

The results of EPA's calculations are shown in Table A5-8. The table presents 95% upper confidence bounds and 5% lower confidence bounds for the marginal value per fish for each species in each region. These bounds can be used to estimate upper and lower confidence bounds for the welfare gain from eliminating baseline I&E losses or reducing I&E losses under each regulatory analysis option. Refer to the regional recreational results chapters for detail on the specific calculations.

Table A5-8: Confidence Bounds on Marginal Recreational Value per Fish, Based on the Krinsky and Robb Approach[a]

Species	California	North Atlantic	Mid-Atlantic	South Atlantic	Gulf of Mexico	Great Lakes	Inland
5% Lower Confidence Bounds[b]							
Small game	$3.34	$1.58	$1.67	$1.96	$2.05		$1.19
Flatfish	$3.93	$2.91	$2.80	$2.91			
Other saltwater	$1.31	$1.31	$1.34	$1.48	$1.46		
Salmon						$8.42	
Walleye/pike						$2.12	$1.85
Bass						$4.90	$4.45
Panfish			$0.48			$0.74	$0.48
Trout						$5.87	$1.22
Unidentified	$1.37	$1.32	$1.39	$1.49	$1.64	$3.59	$1.05
95% Upper Confidence Bounds[b]							
Small game	$11.16	$15.52	$14.55	$11.60	$10.79		$16.82
Flatfish	$16.94	$8.70	$8.07	$7.68			
Other saltwater	$4.75	$4.82	$4.54	$3.91	$3.77		
Salmon						$14.83	
Walleye/pike						$5.69	$6.51
Bass						$10.64	$12.96
Panfish			$1.63			$1.72	$1.63
Trout						$10.79	$4.62
Unidentified	$5.00	$4.86	$5.58	$3.95	$5.94	$7.68	$3.36

[a] All values are in 2004$.

[b] Upper and lower confidence bounds based on results of the Krinsky and Robb (1986) approach.

Source: U.S. EPA analysis for this report.

A5-5.2 Variable Assignments for Independent Regressors

The per fish values estimated from the model depend on the values of the input variables in the meta-analysis. EPA assigned values to the input variables based on established economic theory and characteristics of the affected species and regions. However, because the input values for some variables are uncertain, the resulting per fish values and benefits estimates also include some degree of uncertainty.

A5-5.3 Other Limitations and Uncertainties

In addition to the limitations and uncertainties involved with the study data and model estimation, which are discussed in section A5-3.3e, there are limitations and uncertainties involved with the calculation of per fish values from the model, and with the use of those values to estimate the welfare gain resulting from the regulatory analysis options considered for the 316(b) regulation.

The validity and reliability of benefit transfer — including that based on meta-analysis — depends on a variety of factors. While benefit transfer can provide valid measures of use benefits, tests of its performance have provided mixed results (e.g., Desvousges et al., 1998; Vandenberg et al., 2001; Smith et al., 2002). Nonetheless, benefit transfers are increasingly applied as a core component of benefit cost analyses conducted by EPA and other government agencies (Bergstrom and De Civita, 1999; Griffiths, Undated). Smith et al. (2002, p. 134) state that "nearly all benefit cost analyses rely on benefit transfers, whether they acknowledge it or not." Given the increasing [or as Smith et al. (2002) might argue, universal] use of benefit transfers, an increasing focus is on the empirical properties of applied transfer methods and models.

An important factor in any benefit transfer is the ability of the study site or estimated valuation equation to approximate the resource and context under which benefit estimates are desired. As is common, the meta-analysis model presented here provides a close but not perfect match to the context in which values are desired. For example, although most of the Inland studies take place in the Great Lakes region, the "50 MGD All Waterbodies" option affects sites all across the Inland region. However, EPA believes that regional differences in per fish values for specific Inland species are relatively small.

The final area of uncertainty related to the use of the regression results to calculate regulatory benefits is uncertainty in the estimates of I&E. There are a number of reasons why recreational losses due to I&E may be higher or lower than expected. Projected changes in recreational catch may be underestimated because cumulative impacts of I&E over time are not considered. In particular, I&E estimates include only individuals directly lost to I&E, not their progeny. Additionally, the interaction of I&E with other stressors may have either a positive or negative effect on recreational catch. Finally, in estimating recreational fishery losses, EPA used I&E data provided by facilities, which in some case are more than 20 years old. While EPA used the most current data available, they may not reflect current conditions.

Chapter A6: Qualitative Assessment of Non-Use Benefits

Chapter Contents

A6-1 Public Policy Significance of Ecological Improvements from the Regulatory Analysis Options for Phase III Facilities A6-2
  A6-1.1 Effects on Depleted Fish Populations......................................A6-2
  A6-1.2 Ecosystem Effects...........................A6-5

Introduction

Comprehensive estimates of total resource value include both use and non-use values, such that the resulting total value estimates may be compared to total social cost. “Non-use values, like use values, have their basis in the theory of individual preferences and the measurement of welfare changes. According to theory, use values and non-use values are additive” (Freeman, 1993).[1] Therefore, use values alone may understate total social values. Recent economic literature provides substantial support for the hypothesis that non-use values are greater than zero. Moreover, when small per capita non-use values are held by a substantial fraction of the population, they can be very large in the aggregate. While the general proposition is true, in this specific context we have not been able to determine the magnitude of non-use values. Both EPA’s own *Guidelines to for Preparing Economic Analysis* and OMB’s Circular A-4, governing *Regulatory Analysis,* support the need to assessing non-use values (U.S. EPA, 2000a; U.S. OMB, 2003).

Given that aquatic species without any direct uses account for a large portion of cooling water intake structure losses, a comprehensive estimate of the welfare gain from reduced impingement and entrainment (I&E) losses should include an estimate of non-use benefits.[2] Stated preference methods, or benefit transfers based on stated preference studies, are the generally accepted techniques for estimating non-use values. Stated preference methods rely on surveys that assess individuals’ stated willingness-to-pay (WTP) for specific ecological improvements, such as increased protection of fishery resources.

EPA attempted to measure non-use benefits in monetary terms, as suggested by EPA’s own guidance and OMB’s Circular A-4 (U.S. EPA, 2000a; U.S. OMB, 2003). Using the benefit transfer technique requires adequate empirical valuation studies. No empirical studies were found that estimated non-use values for impacts on fish alone. Thus, EPA needed to pursue developing a stated preference survey. EPA began designing a stated preference survey to separately estimate total value (including non-use value) of fish impacts when work on this rule began. EPA received OMB approval in August 2005, of an Information Collection Request to conduct focus groups for survey design (see docket EPA-HQ-OW-2004-0020). EPA designed a survey, and conducted an external peer review of the survey instrument and analysis plan, completed in February 2006 (Versar, 2006). Peer reviewers provided suggestions to improve the reliability of the results. To make those recommended changes, receive OMB approval for the changes, then conduct the revised survey, and analyze the results would likely have take several months. Owing to the June 1, 2006 Consent Decree deadline, these suggestions could not be incorporated in time for today’s action. For more details on development of the survey, see memorandum entitled “Development of Willingness to Pay Survey Instrument for Section 316(b) Phase III Cooling Water Intake Structures” (Abt Associates, 2006; DCN 9-4826).

---

[1] According to Freeman (1993), this additive property holds under traditional conditions related to resource levels and prices for substitute goods in the household production model.

[2] For detail on the number and percentage of fish directly valued, see section A3-4.1 of this report.

To assess the public policy significance or importance of the ecological gains from the regulatory analysis options considered for the final regulation for Phase III facilities, EPA collected and developed relevant information to enable the Agency to consider non-use benefits qualitatively. This assessment is discussed below.

A6-1 Public Policy Significance of Ecological Improvements from the Regulatory Analysis Options for Phase III Facilities

Changes in cooling water intake system (CWIS) design or operations resulting from the section 316(b) regulations for Phase III facilities would be expected to reduce I&E losses of fish, shellfish, and other aquatic organisms and, as a result, would increase the numbers of individuals present and benefit local and regional fishery populations. Depending on the nature of the reduced losses and on the conditions at the site, this may ultimately contribute to the enhanced environmental functioning of affected waterbodies and associated ecosystems. Specific ecological benefits that may occur due to enhanced environmental functioning of affected waterbodies resulting from the regulatory analysis options considered for Phase III facilities are described in sections A6-1.1 and A6-1.2.

A6-1.1 Effects on Depleted Fish Populations

EPA believes that reducing fish mortality from I&E would contribute to the health and sustainability of the affected fish populations by lowering the overall level of mortality for these populations. Fish populations suffer from numerous sources of mortality; some are natural and others are anthropogenic. Natural sources include weather, predation by other fish, and the availability of food. Human impacts that affect fish populations include fishing, pollution, habitat changes, and I&E losses at CWIS. Fish populations decline when they are unable to sufficiently compensate for their overall level of mortality. Lowering the overall mortality level increases the probability that a population will be able to compensate for mortality at a level sufficient to maintain the long-term health of the population. In some cases, I&E losses may be a significant source of anthropogenic mortality to depleted fish stocks. For example, damaged saltwater fish stocks affected by I&E include winter flounder, red drum, and rockfishes (NMFS, 2003b). I&E also affects species native to the Great Lakes such as lake whitefish and yellow perch whose populations have dramatically declined in recent years (Wisconsin DNR, 2003; U.S. DOI, 2004). See Table A6-1, below, for more information regarding the status of depleted marine, nonsalmonid, stocks.

The public importance of restoring healthy fisheries and of achieving recovery of depleted fish stocks is reflected in actions taken by the Federal and State Agencies to reduce fishing pressure on these fish stocks. Actions taken by the Federal and regional government agencies include buying fishing licenses and fishing vessels at substantial public expense and imposing restrictions on commercial and recreational catch. Fishing restrictions impose limitations on those who make a living from fishing or participate in recreational fishing. Another example of the public value of fishery resources is a large-scale ecosystem restoration program that includes the native species recovery in the Great Lakes Basin (U.S. DOI, 2004).[3]

The Agency believes that reducing fish mortality from I&E along with other measures would contribute to recovery of damaged fish populations.

---

[3] Habitat restoration activities can be targeted to achieve ecological benefits at either the community or individual species level and are critical for preserving aquatic biodiversity throughout the Great Lakes.

Table A6-1: Depleted Marine, Nonsalmonid, NMFS-Managed Fish Stocks Subject to I&E

Stock or Stock Complex	Overfishing?[a]	Overfished?[b]	Approaching Overfished?[c]	Rebuilding from a Depleted State?	Stock Region
American shad	Y	Y	N/A		Atlantic stock
Atlantic sturgeon	N	Y	N/A		Atlantic stock
River herring	Y	Y	N/A		Atlantic stock
Weakfish	N	Y	N/A		Atlantic stock
Red drum	N	Y	N/A	Y	Gulf of Mexico stock
King mackerel	N	N	N	Y	Gulf of Mexico stock
Bluefish	N	N	N	Y	Mid-Atlantic stock
Black sea bass	N	N	N	Y	Mid-Atlantic stock
Butterfish	N	Y	N/A	Y	Mid-Atlantic stock
Summer flounder	Y	N	N	Y	Mid-Atlantic stock
Scup	Y	Y	N/A	Y	Mid-Atlantic stock
Barndoor skate	N	N	N	Y	New England FMC stock
Cod — Georges Bank	Y	Y	N/A	Y	New England FMC stock
Cod — Gulf of Maine	Y	Y	N/A	Y	New England FMC stock
Pollock	N	N	N	Y	New England FMC stock
Silver hake — Southern Georges Bank/ Middle Atlantic	?	N	N	Y	New England FMC Stock
Thorny skate	N	Y	N/A	Y	New England FMC stock
Windowpane flounder — Southern New England/Middle Atlantic	N	Y	N/A	Y	New England FMC stock
Winter flounder — Georges Bank	Y	N	N		New England FMC stock
Winter flounder — Southern New England/Middle Atlantic	Y	Y	N/A	Y	New England FMC stock
Yellowtail flounder — Cape Cod/Maine	Y	Y	N/A	Y	New England FMC stock
Yellowtail flounder — Georges Bank	Y	Y	N/A	Y	New England FMC stock
Yellowtail flounder — Southern New England/Middle Atlantic	Y	Y	N/A	Y	New England FMC stock
Black rockfish — north	Y	N	N		Pacific stock
Canary rockfish	N	Y	N/A	Y	Pacific stock
Darkblotched rockfish	N	Y	N/A	Y	Pacific stock
Shortspine thornyhead	Y	N	N		Pacific stock

Table A6-1: Depleted Marine, Nonsalmonid, NMFS-Managed Fish Stocks Subject to I&E

Stock or Stock Complex	Overfishing?[a]	Overfished?[b]	Approaching Overfished?[c]	Rebuilding from a Depleted State?	Stock Region
Widow rockfish	N	N	N	Y	Pacific stock
Yelloweye rockfish	N	Y	N/A	Y	Pacific stock
Yellowtail rockfish	N	N	N		Pacific stock
Black sea bass	Y	Y	N/A	Y	South Atlantic stock
Red drum	Y	?	N/A	Y	South Atlantic stock

[a] Is the stock currently experiencing fishing at an unsustainable level?

[b] Is the stock overfished (i.e., is it depleted below 20% of historical unfished levels)?

[c] Is it estimated that the stock will reach an overfished condition within 2 years (by the 4th quarter of 2007)?

Source: NOAA, 2005.

A6-1.2 Ecosystem Effects

The aquatic resources affected by cooling water intake structures provide a wide range of services. Ecosystem services are the physical, chemical, and biological functions performed by natural resources and the human benefits derived from those functions, including both ecological and human use services (Daily, 1997; Daily et al., 1997). Scientific and public interest in protecting ecosystem services is increasing with the recognition that these services are vulnerable to a wide range of human activities and are difficult, if not impossible, to replace with human technologies (Meffe, 1992).

In addition to their importance in providing food and other goods of direct use to humans, the organisms lost to I&E may be critical to the continued functioning of the ecosystems of which they are a part. Fish are essential for energy transfer in aquatic food webs (Summers, 1989), regulation of food web structure, nutrient cycling, maintenance of sediment processes, redistribution of bottom substrates, regulation of carbon fluxes from water to the atmosphere, and maintenance of aquatic biodiversity (Peterson and Lubchenco, 1997; Postel and Carpenter, 1997; Holmlund and Hammer, 1999; Wilson and Carpenter, 1999). Examples of ecological services that may be disrupted by I&E include:

- decreased numbers of ecological keystone, rare, sensitive, or threatened and endangered species;
- decreased numbers of popular commercial and recreational fish species that are not fished, perhaps because the fishery is closed;
- increased numbers of exotic or disruptive species that compete well in the absence of species lost to I&E (I&E may also help remove some exotic or disruptive organisms);
- disruption of ecological niches and ecological strategies used by aquatic species;
- disruption of energy transfer through the food web;
- decreased local biodiversity;
- disruption of predator-prey relationships;
- disruption of age class structures of species; and
- disruption of natural succession processes.

Many of these services can only be maintained by the continued presence of all life stages of fish and other aquatic species in their natural habitats. Reducing I&E losses could contribute to restoring (or preserving) the biological integrity of the ecosystems of substantial national importance.

a. Effects on saltwater ecosystems

In the 1987 amendments to the CWA, Congress established the National Estuary Program because the "Nation's estuaries are of great importance to fish and wildlife resources and recreation and economic opportunity. [, and to] maintain the health and ecological integrity of these estuaries is in the national interest" (Water Quality Act, 1987). So far, there are 28 estuaries designated under the National Estuary Program (NEP). In addition, the largest estuary in the United States, Chesapeake Bay, is protected under its own federally mandated program, separate but related to NEP. Table A6-2 shows estuaries from which the sample Phase III facilities draw water. Of the 17 estuaries affected by the surveyed Phase III facilities, 12 are nationally significant estuaries designated under NEP or the Chesapeake Bay Program. Nine, five, and seven of the 17 estuaries affected by the surveyed Phase III facilities have facilities that would also be subject to technology requirements under the "50 MGD for All Waterbodies" option, the "200 MGD for All Waterbodies" option, and the "100 MGD for Certain Waterbodies" option, respectively.

Substantial federal and state resources have been directed to NEP to enhance conservation of and knowledge about the estuaries designated under this program. Since 1998, more than $95 million has been devoted to NEP to benefit the health of the nationally significant estuaries (NEP, 2004; U.S. EPA, 2004c). These expenditures reflect high public values for restoring (or protecting) the biological integrity of the ecosystems of substantial national importance.

Table A6-2: Estuaries Affected by Phase III Facilities

Region	Estuaries Affected by Potentially Regulated Phase III Facilities[a]	Designated Under NEP or the Chesapeake Bay Program[b]	50 MGD All	200 MGD All	100 MGD CWB
California	Honker Bay (San Francisco Bay)	✓			
	Kaulakahi Channel				
North Atlantic	San Pablo Bay (San Francisco Bay)	✓	✓		
	Boston Bay (Massachusetts Bays)	✓	✓	✓	✓
	Fishers Island Sound (Long Island Sound)	✓	✓		✓
	Penobscot Bay				
Mid-Atlantic	Chesapeake Bay (Chesapeake Bay Program)	✓	✓		
	Delaware Bay (Delaware Estuary)	✓	✓	✓	✓
	Fishing Bay (Chesapeake Bay Program)	✓			
	Long Island Sound (Long Island Sound)	✓			
	Newark Bay (New York/New Jersey Harbor)	✓	✓	✓	✓
	Upper Bay (New York/New Jersey Harbor)	✓			
South Atlantic	Savannah River Estuary				
Gulf of Mexico	Christmas Bay (Galveston Bay)	✓	✓	✓	✓
	Galveston Bay (Galveston Bay)	✓	✓		✓
	Lavaca Bay				
	Vermilion Bay		✓	✓	✓

[a] This estimate is based on a total of 314 sample facilities, which represent 629 potentially regulated sample-weighted facilities. The locations of non-sampled facilities are unknown and could not be included in this analysis. Facilities subject to BPJ requirements are located on these estuaries.

[b] Based on estuaries included in EPA's National Estuary Program and the Chesapeake Bay Program.

Source: U.S. EPA, 2006b.

b. Effects on freshwater ecosystems

Reducing I&E at Phase III facilities may also benefit freshwater ecosystems of national significance, including the Great Lakes Basin and Mississippi River. These waterbodies are subject to large-scale ecosystem restoration efforts that are good indicators of great public importance of restoring the ecological health of these ecosystems (Northeast Midwest Institute, 2004; The Upper Mississippi River Basin Association, 2004; U.S. DOI, 2004; USFWS, 2004). The ecosystem restoration efforts focus on many issues, including coastal habitat restoration, protection of fish species, conservation of migratory birds and endangered species. For example, between 1992 and 2001, more than $17 million was devoted to projects to restore and conserve the Great Lakes ecosystem; $102 million was spent on improving the Mississippi River ecosystem (Brescia, 2002; U.S. EPA, 2004b). Reducing I&E of aquatic organisms may improve the quality of aquatic habitat and contribute to improvement of the biological integrity and health of these ecosystems.

Finally, reducing I&E in waterbodies that do not have a national significance may contribute to restoration or protection of ecosystems of regional or local importance.

Chapter A7: Entrainment Survival

Introduction

Chapter Contents

A7-1 The Causes of Entrainment Mortality A7-1
  A7-1.1 Fragility of Entrained Organisms A7-1
  A7-1.2 Thermal Stress A7-2
  A7-1.3 Mechanical Stress A7-2
  A7-1.4 Chemical Stress A7-2
A7-2 Factors Affecting the Determination of Entrainment Survival A7-2
A7-3 Detailed Analysis of Entrainment Survival Studies Reviewed A7-9
A7-4 Discussion of Review Criteria A7-10
  A7-4.1 Sampling Design and Method A7-10
  A7-4.2 Operating Conditions During Sampling A7-12
  A7-4.3 Survival Estimates A7-13
A7-5 Applicability of Entrainment Survival Studies to Other Facilities A7-15
A7-6 Conclusions A7-15

To calculate benefits associated with entrainment reduction, EPA used the assumption that all organisms passing through a facility's cooling water system would experience 100% mortality. This assumption was recommended in EPA's 1977 Guidance for Evaluating the Adverse Environmental Impact of Cooling Water Intake Structures on the Aquatic Environment: Section 316(b) P.L. 92-500 (U.S. EPA, 1977). This is also the basic assumption currently used in the permitting programs for section 316(b) in Arizona, California, Hawaii, Louisiana, Maine, Maryland, Massachusetts, Minnesota, Nevada, New Hampshire, Ohio, and Rhode Island (personal communication, I. Chen, U.S. EPA Region 6, 2002; personal communication, P. Colarusso, U.S. EPA Region 1, 2002; personal communication, G. Kimball, 2002; personal communication, M. McCullough, Ohio EPA, 2002; McLean and Dieter, 2002; personal communication, R. Stuber, U.S. EPA Region 9, 2002).

EPA obtained 37 entrainment survival studies conducted at 22 individual power producing facilities and conducted a detailed review. EPA also reviewed a report prepared for the Electric Power Research Institute (EPRI) (EA Engineering, Science, and Technology, 2000) which summarized the results of 36 entrainment studies, 31 of which were the same studies reviewed by EPA. The intent of EPA's review was to determine the soundness of the findings behind the entrainment survival studies and to evaluate whether the assumption of 100% entrainment mortality is appropriate for use in the national benefits assessment for Phase III facilities to compare to the costs of installing the best technology available for minimizing adverse environmental impact.

A7-1 The Causes of Entrainment Mortality

A7-1.1 Fragility of Entrained Organisms

Cooling water intake structures entrain many species of fish, shellfish, and macroinvertebrates. These species are most commonly entrained during their early life stages, as eggs, yolk-sac larvae (YSL), post yolk-sac larvae (PYSL), and juveniles, because of their small size and limited swimming ability. In addition to having limited or no mobility, these early life stages are very fragile and thus susceptible to injury and mortality from a wide range of factors (Marcy, 1975). For these reasons, entrained eggs and larvae experience high mortality rates as a result of entrainment. The three primary factors contributing to the mortality of organisms entrained in cooling water systems are thermal stress, mechanical stress, and chemical stress (Marcy, 1975). The relative contribution of each of these factors to the rate of mortality of entrained organisms can vary among facilities, based on the nature of their design and operations as well as the sensitivity of the species entrained (Marcy, 1975; Beck and the Committee on Entrainment, 1978; Ulanowicz and Kinsman, 1978). These three primary factors are discussed in more detail below.

A7-1.2 Thermal Stress

Facilities use cooling water as a means of disposing of waste heat from facility operations. Thus, organisms present in the cooling water are exposed to rapid increases in temperatures above ambient conditions when passing through the cooling water system. This thermal shock causes mortality or sublethal effects that affect further growth and development of entrained eggs and larvae (Schubel et al., 1978; Stauffer, 1980). The magnitude of thermal stress experienced by organisms passing through a facility's cooling system depends on facility-specific parameters such as intake temperature, maximum temperature, discharge temperature, duration of exposure to elevated temperatures through the facility and in the mixing zone of the discharge canal, the critical thermal maxima of the species, and delta T (ΔT, i.e., the difference between ambient water temperature and maximum water temperature within the cooling system) (Marcy, 1975; Schubel et al., 1978). The extent of the effect of thermal stress can also vary among the species and life stages of entrained organisms (Schubel et al., 1978; Stauffer, 1980).

A7-1.3 Mechanical Stress

Entrained organisms are also exposed to significant mechanical stress during passage through a cooling system, which also causes mortality. Types of mechanical stress include effects from turbulence, buffeting, velocity changes, pressure changes, and abrasion from contact with the interior surfaces of the cooling water intake structure (Marcy, 1973; Marcy et al., 1978). The extent of the effect of mechanical stress depends on the design of the facility's cooling water intake structure and the capacity utilization of operation. Some studies have suggested that mechanical stress may be the dominant cause of entrainment mortality at many facilities (Marcy, 1973; Marcy et al., 1978). For this reason, it has been suggested that the only effective method of minimizing adverse effects to entrained organisms is to reduce the intake of water (Marcy, 1975).

A7-1.4 Chemical Stress

Chemical biocides are occasionally used within cooling water intake structures to remove biofouling organisms. Chlorine is the active component of the most commonly used biocides (Morgan and Carpenter, 1978; Morgan, 1980). These biocides are used in concentrations sufficient to kill organisms fouling the cooling system structures, and thus cause mortality to the organisms entrained during biocide application. The extent of the effect of chemical stress depends on the concentration of biocide and the timing of its application. Eggs may be less susceptible to biocides than larvae (Lauer et al., 1974; Morgan and Carpenter, 1978). Tolerance to biocides may also vary according to species. However, most species have been shown to be affected at low concentrations, <0.5 ppm, of residual chlorine (Morgan and Carpenter, 1978).

A7-2 Factors Affecting the Determination of Entrainment Survival

There are many challenges that must be overcome in the design of a sampling program intended to accurately establish the magnitude of entrainment survival (Lauer et al., 1974; Marcy, 1975; Coutant and Bevelhimer, 2001). Samples are almost certain not to be fully representative of the community of organisms experiencing entrainment. Some species are extremely fragile and disintegrate during collection or when preserved, and are thus not documented when samples are processed (Boreman and Goodyear, 1981). This is particularly true for the most fragile life stages, such as eggs and yolk-sac larvae of many species. All sampling devices are selective for a certain size range of organisms, so a number of sampling methods would have to be employed to accurately sample the broad size range of organisms subject to entrainment. The relative ability of different organisms to avoid sampling devices also determines abundance and species composition estimated from samples (Boreman and Goodyear, 1981). This avoidance ability varies with the size, motility, and condition of the organisms. If dead or dying organisms tend to settle out, then sampling will be selective for the live, healthy specimens (Marcy, 1975). If, on the other hand, the healthy, more motile specimens are able to avoid sampling gear, the sampling will tend to be selective for dead or stunned specimens. The patchy distribution of many species (Day et al., 1989; Valiela, 1995) creates difficulties in developing precise estimates of organism densities (Boreman and Goodyear, 1981). The patchier the distribution, the greater the number of samples required to reduce the uncertainty associated with the density estimates to an acceptable level.

The factors just discussed affect the ability to accurately establish the type and abundance of organisms present at the intake and discharge of a cooling water system. A second suite of factors, superimposed on the first, affects the ability to estimate the percentages of those organisms that are alive and dead at those two locations. The greatest challenge to be overcome is posed by the fragility of the organisms being studied. The early life stages of most species are so fragile that they may experience substantial mortality simply due to being sampled, both from contact with the sampling gear and in being handled for subsequent evaluation. For example, Marcy (1973) reported on the effects of current velocity on percent mortality of ichthyoplankton taken in plankton nets, and found sampling mortality of 18% at velocities of 0.3 to 0.6 m/sec. The loss or damage of organisms beyond identification during plant passage causes overestimations of the true fraction of live organisms in the discharge samples, because the disintegrated organisms are extruded from the sampling device (Boreman and Goodyear, 1981).

The entrainment survival studies addressed in this review quantified survival by estimating the percentage of organisms categorized as alive, stunned, or dead present in samples collected at the intake and discharge locations of a facility. In the studies reviewed, a variety of methods were used to determine the physiological state of sampled organisms, ranging from placing the sampled organisms in various types of holding containers for observation to the use of devices specifically designed for assessment of larval survival, such as a larval table. A variety of criteria was also used in these studies to categorize the physiological status of the organisms, such as opacity as an indicator of a dead egg, and movement of a larva in response to being touched as an indicator of being alive or stunned. The lack of standardized procedures applied for assessing physiological condition in all of the studies reviewed made comparisons of the study findings difficult.

When quantifying entrainment survival, these studies used the estimates of the percentage dead from samples collected at the intake as controls to correct the samples at the discharge for mortality associated with natural causes and with sampling and handling stress. The use of intake samples as controls requires the assumption that sampling- and handling-induced mortality rates be the same at the intake and discharge, which, in turn, requires that sampling methods and conditions be nearly identical in both locations (Marcy, 1973). This requirement is difficult to meet at most facilities because of the differences in the physical structures and hydrodynamic conditions at intakes and discharges (e.g., frequently high velocity, turbulent flow at discharges versus lower velocity, laminar flows at intakes). In many cases, the location and design of the cooling water intake and discharge structures may preclude use of the same type of sampling gear in both locations. Another assumption implicit in this approach is that mortality due to entrainment is entirely independent of mortality due to sampling and handling and that there is no interaction between these stresses, an assumption that is acknowledged but never proven in the studies reviewed.

The percent alive in the intake control is frequently well below 100% because these fragile organisms experience substantial mortality from stresses caused by being collected. An additional factor contributing to the less than 100% alive in intake samples is that some dead organisms may be present in the water column being sampled because of natural mortality or recirculation of water discharged from the cooling system. In many studies, the survival in the intake sample is extremely low; for example, the intake survival for bay anchovy was 0% in studies conducted at Bowline (Ecological Analysts, 1978a), Brayton Point (Lawler, Matusky & Skelly Engineers, 1999), and Indian Point (Ecological Analysts, 1978c; EA Engineering, Science, and Technology, 1989). The studies reviewed corrected their discharge survival estimates to account for the control sample mortality by using the percent alive in the intake control samples in the following manner. First, the proportion initially alive at the intake (P_I) and discharge (P_D) samples was determined, for each species in most cases, using the following equation:

$$P_I \text{ or } P_D = \frac{\text{Number of alive and stunned organisms}}{\text{Total number of organisms collected}}$$

Using the intake proportion as the control, initial percent entrainment survival (S_I) was then calculated using the following equation:

$$S_I = \left[\frac{P_D}{P_I}\right] \times 100$$

When latent mortality was studied, a sample of the alive and stunned organisms from the initial entrainment survival determination was observed for a given period of time. The latent survival rate calculated is the proportion of those that remained alive after a given period of time from only those that survived initially and not the total number sampled. The latent percent survival (S_L) was determined using the following equation:

$$S_L = 100 \times \left[\frac{\dfrac{\#\text{ of alive organisms after a given time from discharge samples}}{\#\text{ of organisms initially sampled alive or stunned indischarge samples}}}{\dfrac{\#\text{ of alive organisms after a given time from intake samples}}{\#\text{ of organisms initially sampled alive or stunned in intake samples}}}\right]$$

Entrainment survival was then calculated by adjusting the initial entrainment survival with latent entrainment survival using the following equation:

$$\text{Entrainment survival (\%)} = S_I \times S_L$$

A variation of this formula, specifically Abbott's formula, is used for acute toxicity testing in the Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms (U.S. EPA, 2002; EPA-821-R-02-012) and in testing of pesticides and toxic substances in Product Performance Test Guidelines OPPTS 810.3500 Premises Treatments (U.S. EPA, 1998; EPA-712-C-98-413), to adjust mortality for the possibility of natural deaths occurring during a test. This formula is intended to account for acceptable levels of unavoidable control mortality in the range of 5 to 10% (Newman, 1995). Abbott's formula is as follows:

$$\text{Corrected mortality} = 1 - \left[\frac{1 - \text{proportion dead in treatment}}{1 - \text{proportion dead in control}}\right]$$

This method of correcting for control mortality is often used in toxicological experiments in which organisms in concurrent control and experimental samples experience identical conditions except for the stressor that is the subject of study, and, as already noted, this method is applied when control mortalities, from stress due to holding or sampling and from natural causes, are generally low (less than 10%). In entrainment survival studies, sampling conditions at the intake and discharge are seldom identical. Also, the initial mortalities in the intake samples are often much higher than 5 or 10% and sometimes higher than the mortality in the discharge samples.

In addition, the assumption that mortality due to entrainment is entirely independent of mortality due to sampling and handling with no interaction between these stresses is not true. The dead organisms observed in the intake samples comprise organisms that died before sampling from natural conditions, organisms that died from the stress of sampling and sorting, and possibly organisms that died from previous passages through the cooling water system at facilities where water is recirculated. The dead organisms observed in the discharge samples comprise organisms that died before passage through the facility from natural conditions, organisms that died from the stresses associated with entrainment as described above, and organisms that died from the stress of sampling and sorting. The fundamental difference between the extent of the effect of sampling stress in the intake and the discharge samples is that the discharge samples are exposed to sampling stress after they have been exposed to entrainment stress. Thus the most vulnerable organisms have already died because of entrainment and would not be alive at the time of sampling to die from that stress. By correcting discharge samples for sampling and natural deaths using the intake results, the assumption is made that the mortality in the discharge sample is the result of the same probability of death due to sampling as in the intake sample and only the additional mortality is due to the stress of entrainment. When intake survival (P_I) is less than discharge survival (P_D), the use of the equation for entrainment survival (S_I) results in a calculation of 100% survival even though the majority of organisms may be dead in both samples (EA Engineering, Science, and Technology, 2000). However, in the intake sample, much of the mortality may be due to sampling stress, whereas in the discharge sample, much of the mortality may be due to entrainment stress. Additionally, the initial survival estimates may be overestimations of survival due to the disintegration of entrained organisms and their subsequent extrusion through the sampling gear (Boreman and Goodyear, 1981). For all of the reasons described above, the applicability of this equation for determining entrainment survival by correcting discharge survival with intake survival is questionable. Also, the statistical attributes of these calculated mortality proportions are often not addressed. The higher and more variable the intake sample mortality percentages, the greater the degree of uncertainty that would be expected to be associated with the resultant entrainment survival estimates.

An additional factor that was not accounted for in all the studies reviewed was the fate of organisms discharged into receiving waters after passage through the cooling system. Latent mortality studies were intended to document delayed mortality of organisms that were lethally injured or stressed during entrainment but were not killed immediately. Some studies (e.g., Lauer et al., 1974) also reported that some fish larvae surviving entrainment behaved normally when maintained in laboratory conditions for extended periods of time, eating and growing normally. However, larvae that did not experience immediate mortality from lethal stresses were discharged into receiving waters under conditions substantially altered from the normal environment in which they were present before entrainment and under conditions very dissimilar to those experienced under laboratory conditions. Any naturally occurring vertical positioning of the organisms within the water column would be disrupted (Day et al., 1989), and the turbulence and velocities present in discharge locations would be unlike the environmental conditions they experienced before entrainment. Under such altered conditions, their normal ability to feed or escape predation is compromised. In addition, thermal shock can disrupt further development of eggs and larvae even if they survive entrainment (Schubel et al., 1978). The potential for such phenomena to occur and the magnitude the effect may have on any possible survival of entrained organisms would be nearly impossible to confirm or refute through field studies. However, were these phenomena to occur, they would result in mortalities beyond and in addition to the initial and latent mortalities that were calculated in the studies reviewed.

The factors discussed above served as the basis for EPA's review of the entrainment survival studies. Table A7-1 presents summary information collected directly from each of the original studies reviewed.

Table A7-1: Summary of Entrainment Survival Study Results

Facility	Sampling Period	Number of Samples and Days	Species	Number Sampled at Intake	Number Sampled at Discharge	Survival Study	Initial Discharge Survival	Latent Discharge Survival	Study Survival Estimate
Anclote	September-November 1985	120 samples, 8 days	Fish larvae	109	474	Initial and 24 hour latent	8-47%	-	27-62%
			Amphipods	5,185	4,662		29-58%	-	49-73%
			Chaetognatha	1,549	1,927		28-35%	-	67-72%
			Crab larvae	3,007	6,145		74-80%	-	21-100%
			Caridean shrimp	2,728	1,766		45-66%	-	64-81%
Bergum Power Station	April-June 1976	Unknown #, 6 days	Smelt	Unknown	322	Initial	10-28%	-	10-41%
			Perches	Unknown	826		32-74%	-	39-82%
Bowline Point	June-July 1975	Unknown #, unknown days	Striped bass	141	111	Initial and 96 hour latent	74%	23%	70%
			White perch	122	168		68%	26%	100%
			Bay anchovy	2,134	1,317		2%	0%	22%

Table A7-1: Summary of Entrainment Survival Study Results									
Facility	**Sampling Period**	**Number of Samples and Days**	**Species**	**Number Sampled at Intake**	**Number Sampled at Discharge**	**Survival Study**	**Initial Discharge Survival**	**Latent Discharge Survival**	**Study Survival Estimate**
Bowline Point	May-July 1976	Unknown #, 10 days	Striped bass PYSL	118	207	Initial and 96 hour latent	54%	23%	26-77%
			White perch PYSL	54	42		33%	21%	13-84%
			Bay anchovy PYSL	148	1,120		0%	0%	-
			Herrings PYSL	46	83		20%	1%	0-80%
			Atlantic tomcod PYSL	54	17		29%	12%	54%
Bowline Point	March-July 1977	736 samples, 46 days	Striped bass larvae	228	452	Initial and 96 hour latent	71-72%	55-66%	41-100%
			White perch PYSL	26	38		34%	69%	16-62%
			Bay anchovy larvae	634	1,524		0-2%	0%	-
			Herrings PYSL	37	22		23%	5%	51%
			Silverside PYSL	24	56		16%	0%	-
Bowline Point	March-October 1978	609 samples, 40 days	Striped bass PYSL	646	792	Initial and 96 hour latent	52-63%	5-46%	76-100%
			White perch PYSL	190	301		19%	0-5%	52-68%
			Bay anchovy PYSL	325	763		0-3%	0%	-
			Herrings PYSL	271	51		23-63%	0%	-
Bowline Point	May-June 1979	435 samples, 19 days	Striped bass PYSL	77	155	Initial and 96 hour latent	35-41%	8-20%	24-42%
			White perch PYSL	205	191		26-35%	5-8%	32%
			Bay anchovy PYSL	181	89		0-4%	0%	-
			Herrings PYSL	63	92		30-31%	0-3%	0-58%
Braidwood Nuclear	June-July 1988	68 samples, 3 days	All species combined	191	103	Initial	59%	-	100%
Brayton Point	April-August 1997 February-July 1998	6,829 samples, 41 days	Winter flounder	49	965	Initial and 96 hour latent	30-38%	-	90-100%
			Tautog	34	401		4%	-	98-100%
			Windowpane flounder	58	58		29-30%	-	65-67%
			Bay anchovy						
			American sand lance	539	15,896		0%	-	0%
				1,091	2,941		0%	-	100%
Cayuga Generating Plant	May-June 1979	80 samples, 24 days	Suckers	984	649	Initial and 48 hour latent	75-92%	93-98%	87-98%
			Carps and minnows	466	192		12-74%	45-100%	25-86%
			Perches	108	66		43-69%	44-61%	19-59%
Connecticut Yankee	June-July 1970	102 samples, 7 days	Alewife Blueback herring	Unknown	Unknown	Initial	0-8%	-	0-25%
Connecticut Yankee	June-July 1971 and 1972	30 samples, 2 days	Alewife Blueback herring	273	795	Initial	0-24%	-	0-26%
Contra Costa	April-July 1976	Unknown #, 7 days	Striped bass	637	329	Initial	0-50%	-	0-95%
Danskammer Point Generating Station	May-November 1975	372 samples, 29 days	Striped bass PYSL	54	61	Initial and 96 hour latent	39%	3%	95%
			White perch PYSL	36	55		38%	4%	100%
			Herrings PYSL	200	326		20%	0%	80-87%
Fort Calhoun	October 1973-June 1977	Unknown #, 89 days	Ephemeroptera	2,221	2,220	Initial	18-32%	-	92%
			Hydropsychidae	3,690	4,964		47-56%	-	92%
			Chironomidae	2,646	2,925		43-66%	-	84%

Table A7-1: Summary of Entrainment Survival Study Results

Facility	Sampling Period	Number of Samples and Days	Species	Number Sampled at Intake	Number Sampled at Discharge	Survival Study	Initial Discharge Survival	Latent Discharge Survival	Study Survival Estimate
Ginna Generating Station	June and August 1980	255 samples, 20 days	Alewife larvae	54	95	Initial and 48 hour latent	0%	-	-
			Rainbow smelt larvae	31	17		0%	-	0%
Indian Point	June and July 1977	Unknown #, 7 days	Striped bass PYSL	806	518	Initial and 96 hour latent	45-52%	29-36%	85-87%
			White perch PYSL	158	67		15-43%	15-30%	73-89%
			Bay anchovy PYSL	1,254	704		3-4%	0%	18-36%
			Herrings PYSL	100	65		10-11%	0%	40%
Indian Point	May-July 1978	Unknown #, 22 days	Striped bass PYSL	447	1,102	Initial and 96 hour latent	0-34%	0-19%	0-82%
			White perch PYSL	227	392		0-37%	6-15%	0-58%
			Bay anchovy PYSL	500	820		0%	0%	0%
			Herrings PYSL	1,046	1,104		0-8%	0%	0%
Indian Point Generating Station	March-August 1979	Unknown #, 40 days	Atlantic tomcod	266	212	Initial and 96 hour latent	14-46%	15-75%	11-64%
			Striped bass	127	153		62-77%	4-21%	59-75%
			White perch	195	147		24-70%	18%	29-32%
			Herrings	254	186		28%	13%	22-31%
			Bay anchovy	457	485		6%	4%	3-7%
Indian Point Generating Station	April-July 1980	Unknown #, 44 days	Striped bass	227	248	Initial and 96 hour latent	50-81%	60-72%	55-81%
			Bay anchovy	260	588		0-4%	0%	2-4%
			White perch	113	176		0-90%	73%	50-90%
Indian Point Generating Station	May-June 1985	Unknown #, 49 days	Bay anchovy PYSL	106	274	Initial and 48 hour latent	6%	0%	0-24.3%
Indian Point Generating Station	June 1988	Unknown #, 13 days	Striped bass larvae	353	2,710	Initial and 24 hour latent	62-68%	24-44%	60-79%
			Bay anchovy larvae	633	7,391		0-2%	0%	0-25%
Indian River Power Plant	July 1975-December 1976	46 samples, 27 days	Bay anchovy	Unknown	Unknown	Initial and 96 hour latent	Unknown	Unknown	0-100%
			Atlantic croaker						0-100%
			Spot						25-100%
			Atlantic menhaden						0-100%
			Atlantic silverside						0-100%
Muskingum River Plant	1979	No samples	None specified	0	0	None	Intermediate to high potential	-	-
Northport Generating Station	April and July 1980	162 samples, 20 days	American sand lance	29	782	Initial and 48 hour latent	17%	2%	2%
			Winter flounder	13	17		35%	17%	10%
			Bay anchovy	7	11		0%	0%	-
Oyster Creek Nuclear Generating Station	February-August 1985	28 samples, 20 days	Bay anchovy larvae	3,396	3,474	Initial and 96 hour latent	0-71%	0%	0-68%
			Winter flounder larvae	3,935	2,999		32-92%	6-66%	15-84%
Pittsburg Power Plant	April-July 1976	Unknown #, 7 days	Striped bass	196	266	Initial	8-87%	-	12-94%

Table A7-1: Summary of Entrainment Survival Study Results

Facility	Sampling Period	Number of Samples and Days	Species	Number Sampled at Intake	Number Sampled at Discharge	Survival Study	Initial Discharge Survival	Latent Discharge Survival	Study Survival Estimate
Port Jefferson	April 1978	94 samples, 5 days	Winter flounder	36	26	Initial and 96 hour latent	0-23%	50%	65%
			Sand lance	249	191		12-40%	0-10%	25-86%
			Fourbeard rockling	216	144		19-21%	-	73-100%
			American eel	107	96		94-96%	71-96%	100%
			Sculpin	22	17		88%	-	75%
PG&E Potrero	January 1979	25 samples	Pacific herring	546	716	Initial and 96 hour latent	16%	-	70%
Quad Cities Nuclear Station	June 1978	Unknown #, 5 days	Freshwater drum	378	916	Initial and 24 hour latent	0-71%	-	2-62%
			Minnows	278	307		2-75%	-	7-63%
Quad Cities Nuclear Station	April-June 1984	Unknown #, 8 days	Freshwater drum	Unknown	Unknown	Initial and 24 hour latent	Unknown	-	63%
			Carp	Unknown	Unknown		Unknown	-	92-97%
			Buffalo	Unknown	Unknown		Unknown	-	94%
Roseton Generating Station	May-November 1975	672 samples, 41 days	Striped bass PYSL	100	172	Initial and 96 hour latent	62%	6%	38%
			White perch PYSL	77	97		29%	1%	-
			Herrings PYSL	471	833		26%	0%	-
Roseton Generating Station	June-July 1976	Unknown #, 27 days	Striped bass PYSL	93	80	Initial and 96 hour latent	14-43%	-	19-58%
			White perch PYSL	401	349		6-42%	-	11-79%
			Herring PYSL	1,054	645		5-29%	0%	10-59%
Roseton Generating Station	March May-July 1977	Unknown #, unknown days	Striped bass PYSL	427	765	Initial and 96 hour latent	3-29%	18%	6-58%
			White perch PYSL	251	266		0-17%	27%	0-52%
			Herring PYSL	880	1,344		0-5%	0%	0-19%
			Atlantic tomcod YSL	1,178	1,345		16%	40%	41%
Roseton Generating Station	March July-July 1978	256 samples, 30 days	Striped bass PYSL	123	211	Initial and 96 hour latent	27-50%	18%	46%
			White perch PYSL	395	459		0-35%	10%	56-96%
			Herring PYSL	1,274	1,089		0-10%	0%	0%
			Atlantic tomcod PYSL	83	153		33-45%	36%	39%
Roseton Generating Station	May-July 1980	1,431 samples, 42 days	Striped bass PYSL	245	425	Initial and 48 hour latent	46-61%	48-56%	88%
			White perch PYSL	194	366		30-59%	27-62%	67%
			Herring PYSL	812	1,252		7-31%	1-3%	23%
Salem Generating Station	1977-1982	640 samples, 38 days	Spot	66	130	Onsite and simulated studies	74.1%	-	0-76%
			Herrings	8	14		7.1%	0%	2-74%
			Atlantic croaker	-	-		-	-	0-60%
			Striped bass	-	-		-	-	32-46%
			White perch	-	-		-	-	30-70%
			Bay anchovy	-	-		-	-	2-3%
			Weakfish	-	-		-	-	14-56%

A review of the data in Table A7-1 shows that the majority of the studies were conducted at facilities located in a limited geographical region of the country: 24 of the studies were conducted in the northeastern region of the United States. This may explain why these studies provide entrainment survival estimates for relatively few, only 24, species or families of fish. The majority of survival estimates in these studies were for striped bass, white perch, bay anchovy, and herrings. Also, the majority of these studies are over 20 years old, with 25 of the studies conducted in the 1970s. Thus, the results on species composition and abundance are not necessarily indicative of current conditions, with improved water quality due to the enactment of the Clean Water Act in 1972. Entrainment survival in these studies was also estimated with relatively short sampling periods, with the 15 studies using sampling periods of approximately two months long. Also, the sampling periods did not always correspond to peak egg and larval abundance in the waterbody. Twelve of these studies determined that sample sizes of fewer than 100 individuals for a particular species at the discharge station were sufficient to give an accurate estimation of entrainment survival. These small sample sizes are not be sufficient to provide accurate estimates of entrainment survival given that these facilities entrain organisms on the order of millions to billions per year. Also, small sample sizes in conjunction with the high variability of entrainment survival increase the uncertainty associated with these estimations. The small sample sizes allowed for limited study of latent survival, and no facility attempted to study latent physiological effects of entrainment on a species, such as the possible effects on growth rates, maturation, fertility, and vulnerability to natural mortality. The nature of the equation for entrainment survival results in estimates substantially higher than the proportion of survival in the discharge samples because of its use of a correction for mortality in the intake samples, which is often quite high. The fact that the existing studies are characterized by high uncertainty, high variability, and the potential for high bias (Boreman and Goodyear, 1981) complicates efforts to synthesize the various results in a manner that would provide useful generalizations of the results or application to other particular facilities. For these reasons, EPA believes that the reported results do not provide a clear indication as to the extent of entrainment survival significantly above 0% to be used as a defensible assumption to calculate benefits for the section 316(b) rulemaking.

A7-3 Detailed Analysis of Entrainment Survival Studies Reviewed

The summary tables at the end of this chapter provide detailed summary descriptions of each of the 37 studies reviewed. EPA reviewed these studies to determine if they were conducted in a manner that provides adequate representation of the current probability of entrainment survival at the facility. The criteria EPA used to evaluate the studies focused on three main themes: the sampling effort of the study, the operating conditions of the facility during the study, and the survival estimates determined as the result of the study. Specifically, EPA asked the following questions:

Sampling:

- When were samples collected?
- With what frequency were samples collected?
- Were samples collected when organisms were spawning, or at peak abundance?
- What time of day were samples collected?
- What was the number of replicates per sampling date?
- Were the intake and discharge samples collected at the same time so the results can be compared?
- How long was each sample collected?
- What method was used to collect samples?
- At what depth were samples collected?
- What was the location of the samples collected at the intake and discharge?
- Which water quality parameters were measured?
- Were dissolved organic carbon (DOC) and particulate organic carbon (POC) measured?
- What was the velocity at the intake and at the discharge?

Operating conditions during sampling:

- How many generating units at the facility were in operation?
- How many pumps at the facility were in operation?
- What was the intake temperature range, the discharge temperature range, and the ΔT range to which organisms were exposed?
- Were biocides in use?

Survival estimation:

- How many sampling events occurred?
- What was the total number of samples collected?
- What was the total number of organisms collected?
- How many organisms are entrained each year at this facility?
- Did the study take into account fragmented organisms?
- Were the number of organisms collected at the intake and at the discharge comparable?
- What were the most abundant species collected?
- Were stunned larvae included with live larvae in survival estimates?
- Did the facility omit dead and opaque organisms from the count of dead organisms?
- How was latent survival studied?
- Were data sampled from all times and operating conditions combined to determine entrainment survival?
- What were the controls for the study?
- What was the range of intake survival determined by the study?
- What was the range of discharge survival determined by the study?
- How was entrainment survival calculated?
- Were confidence intervals or standard errors calculated?
- Were significant differences tested between intake and discharge survival?
- Was entrainment survival calculated for species with low sample sizes, such as fewer than 100 organisms?
- Was egg survival studied?
- Was there any trend evident in larval survival?
- Were the raw data provided to verify results?
- What was the trend of survival with regard to temperature?
- What was the extent of mechanical mortality?
- What quality control procedures were used?
- Was the study peer reviewed?

A7-4 Discussion of Review Criteria

In this section, the criteria EPA used to review the entrainment survival studies are discussed in depth to give a better indication of the soundness of the science behind a facility's estimate of potential survival.

A7-4.1 Sampling Design and Method

These aspects of the sampling effort are relevant to whether the samples collected are representative of all organisms experiencing entrainment with regard to taxa and size classes, whether the estimates of densities and numbers are accurate and precise, and whether the survival estimates for the intake and discharge can be validly compared (Marcy, 1975; Boreman and Goodyear, 1981). Sampling should be carefully planned to minimize any potential bias (Marcy, 1975; Boreman and Goodyear, 1981). Studies should be conducted throughout the parts of the year when substantial numbers of organisms are entrained. Any possible survival may vary with factors that change seasonally, such as organism size and life stage and ambient water temperature. Most studies attempted to collect samples during times of peak abundance, although the sampling frequency may not have been sufficient to fully capture peak densities. Of those reviewed by EPA, six studies did not correspond with the timing of peak densities at that location.

Even if a study is limited to the early life stages of particular fish or shellfish, survival differences among sizes and life stages and seasonal or temperature-related changes in entrainment survival must be quantified. The timing of the sample collection for an entrainment survival study can influence results in a number of ways, such that results from studies collected during one period may not be representative of potential effects during other periods. For instance, samples collected when the intake temperatures are low or late in a spawning season when larvae are larger can produce estimates of entrainment survival that may be higher than at other times. Thus, studies need to be conducted throughout the entire spawning season to accurately characterize overall entrainment mortality if entrainment survival is found to vary with life stage or size of each species entrained. For the same reason, it may not be appropriate to develop average survival estimates from samples collected under different environmental conditions (in particular under different temperature regimes) and from only parts of a spawning period for a particular species. This was done in almost all the studies reviewed by EPA, which causes their results to be of questionable value. This also makes it difficult for EPA to synthesize the results of these studies into a meaningful average value of entrainment survival to be used in a national benefits assessment.

Many studies collected samples at night to ensure high numbers of organisms in their samples because larvae rise to the surface at night to feed and avoid predation (Marcy, 1975; Day et al., 1989). This practice will bias results because the samples will contain a disproportionate number of live organisms than that which is actually present in the water column. There is evidence that dead organisms will sink to the bottom of the water column after entrainment (Marcy, 1975). Twenty-four studies indicated that most sampling took place at night. For many studies, the depth of sampling is not noted and thus it is unclear whether the samples were collected near the surface, at mid-depth, or near the bottom of the water column. Any potential for bias due to a higher percentage of alive organisms present near the surface could not be assessed.

The method of sampling should be selected to cause the least amount of mortality possible and the mesh size should be fine enough to capture disintegrated or fragmented organisms. Many studies sampled organisms using sampling instruments with mesh size greater than or equal to 500 µm. This may not be fine enough to capture disintegrated or fragmented organisms in the discharge. Attention should be given to the mesh size of sampling instruments to be sure that the targeted sample is not extruded through the mesh.

Intake and discharge sampling should be paired to be sure that the same population of organisms is sampled and subsequently compared. In 12 studies examined, it is unknown if the samples at the intake and discharge were paired. In some studies, samples were not collected at all locations during all sampling events. In other studies, twice as many samples were collected at the discharge than at the intake. Also, in many instances, the intake samples were collected at different generating units of the facility than the discharge samples. Average elapsed times for sample collection were given, and it is unclear if the same elapsed time was used at both locations to give an accurate depiction of organismal densities. The time elapsed during sample collection or the volume of water sampled should be identical in the paired intake and discharge samples to ensure valid comparisons of samples. It was not indicated in any of the studies reviewed whether the same volume of water was sampled in all the intake and discharge samples. If intake samples are to be compared to discharge samples, consistent sampling methods must be used at the two locations so that the samples contain the same density of organisms.

The location of the intake sampling is important because it may contain organisms that already died because of the changes in velocity near the intake. Two studies reviewed collected intake samples after the water had entered the cooling system. The location of the discharge sampling is also important. Samples collected from the end of the discharge canal may not contain organisms that died from passage through the facility because of the tendency of dead organisms to settle out of the water column in the discharge canal. Samples collected from the discharge pipe may not contain organisms that died from thermal effects of entrainment because the samples are collected before the full effects of thermal exposure were experienced. Fourteen studies reviewed collected discharge samples from the discharge pipe. It is also unknown if the samples collected in the discharge canal or from the receiving water contained organisms in the dilution water that bypassed the cooling water system. Five studies reviewed collected discharge samples in the receiving water downstream from the discharge canal, which can result in samples containing organisms that never passed through the cooling water system. The velocity at the intake and discharge should also be recorded to determine the potential to cause mortality. Fourteen of the studies noted the velocity at the intake, at the discharge, or both. For the ones that did not give both intake and discharge velocities, it is unknown whether the velocities at the two sampling sites were comparable, and thus whether the mortalities due to velocity-related sampling stress were comparable at the two locations.

Water chemistry conditions also need to be recorded to be sure conditions are similar at all sampling locations. Water quality parameters include measurements of dissolved oxygen, pH, and conductivity in the through-plant water, at the discharge point, and in the containers or impoundments in which the entrained organism are kept when determining latent mortality. Eighteen studies reviewed gave some indication that water quality parameters were measured. However, it is unclear whether measurements were collected at both the intake and the discharge, and only one study reviewed indicated that water quality parameters were measured in latent mortality studies (EA Engineering, Science, and Technology, 1986).

A7-4.2 Operating Conditions During Sampling

Mortality due to entrainment stress is affected by the operating characteristics of the power facility. The conditions under which the samples are collected are extremely important and, therefore, the results can be assumed to represent possible survival only when the facility is operating under those same conditions and at that time of year, and may not represent any potential for survival at all times. For example, results of studies conducted when the plant was not generating power (and thus not transferring heat to the cooling water) would not be applicable to impacts when it was in full operation. The magnitude of mechanical stress is dependent on the design of the facility's cooling water intake structure. The physical and operating conditions of the facility must be recorded to determine the effect on entrainment survival. The percentage of the maximum load at which the facility is operating must be recorded at the time of sampling to indicate the extent to which organisms are exposed to stress. The number of generating units was highly variable or unknown in many of the studies reviewed. Only one study indicated that the facility operated at peak load to maximize temperature stress during the time of sampling. Eight studies indicated that power was generated during only a portion of time in the sampling period. To fully account for the effects of mechanical stressors on entrainment survival, the study must reflect the speed and pressure changes within the condenser, the number of pumps in operation, the occurrence of abrasive surfaces, and the turbulence within the condenser. In addition, it is important to note the number and arrangement of generating units, parallel or in sequence, which may expose organisms to entrainment in multiple structures. Survival should be studied under the range of facility conditions that may influence survival, for example, intake flow or capacity utilization and ambient (intake) water temperature and ΔT.

The effect of temperature can be species-specific since different fishes have different critical thermal maxima. The maximum temperature to which organisms may be exposed while passing through the facility may cause instant death in some species but not others. To assess the effect of thermal stressors on entrainment survival, the study must determine the temperature regime of the facility. Specifically, the study must record the temperature at both the intake and the discharge point for each component of the facilities system: temperature changes within the system, including the inflow temperature; maximum temperature; ΔT; rate of temperature change; and the temperature of the water to which the organisms are discharged. It is also important to measure the duration of time an organism is entrained and thus exposed to the thermal conditions within the condenser and in the mixing zone of the discharge canal. This information was not provided in the studies reviewed by EPA. Also, in those studies that attempted to relate survival to temperature stress, too few samples were collected at different temperature ranges to give an adequate representation of survival in that range. The EPRI report sorted larval entrainment survival data by discharge temperature and concluded that survivability decreased as the discharge temperature increased (EA Engineering, Science, and Technology, 2000). The lowest probability of larval survival occurred at temperatures greater than 33 °C. In the studies reviewed by EPA, a noticeable decline in survival estimates occurred at discharge temperatures above 30 °C. The amount of time that a facility discharges water in different temperature ranges and survival estimates at that temperature range should be weighted when attempting to determine the survival estimate throughout the year, rather than using an average survival during the sampling period, which may not adequately reflect operating conditions throughout the year.

To properly account for chemical stressors, the timing, frequency, methods, concentrations, and duration of biocide use for the control of biofouling must be determined. The extent to which biocides are routinely used is unknown. The studies reviewed by EPA were all conducted at times when biocides were not in use because the biocide use would be expected to kill all organisms. Thus, the results of these studies do not account for biocide impacts and only reflect other times when biocides are not in use at the particular facility. A reduced survival estimate for the proportion of time when biocides were in use would have to be incorporated into any estimation of annual mean entrainment mortality value for a facility for that estimate to be valid.

A7-4.3 Survival Estimates

Many of the entrainment survival studies reviewed did not account for the extent to which the fragile life stages are fragmented and disintegrated by both sampling and entrainment. Only six of the studies acknowledged that the entrainment survival estimates were indicative only of alive and stunned identifiable organisms out of all those sampled and enumerated that were at least 50% intact. In such circumstances, an important proportion of entrained dead (fragmented) organisms is omitted from the calculated estimate of survival. Entrainment survival studies should not limit their estimates of survival to include only those organisms that are either whole or 50% whole in the sample. For those studies that did not discuss the issue of fragmented organisms, it is unclear how the issue was treated. Several studies indicated that the majority of the sample was mangled or unidentifiable. There is potential for an extremely large number of dead organisms to be excluded from entrainment survival estimates because they are fragmented to the point of being unidentifiable. Studies should account for this fragmentation of organisms by measuring unidentifiable biomass in the samples from the intake and discharge stations. Without taking these organisms into account, entrainment survival estimates will be biased and the results will be higher than that which actually occurs. There are indications that the number of fragmented organisms, which are generally not included in survival estimates, may be high which results in an overestimation of entrainment survival if these fragmented organisms are more prevalent in the discharge. In the proceedings of a conference held in Providence, RI, on January 6, 1972, entitled *Pollution of the Interstate Waters of Mount Hope Bay and its Tributaries in the States of Massachusetts and Rhode Island*, the following regarding fragmentation was quoted ". . . in 1970 when we observed many small transparent larval menhaden in the intake. They were most readily noted by their black eyes. But in the effluent, all we found were eyes. They were torn to pieces" (U.S. EPA, 1972). Foam observed in the discharge (Thomas, 2002) may indicate that fragmentation is substantial. The data summary in Jinks et al. (1981) suggests that a substantial number of fish larvae may be fragmented by mechanical forces and become unrecognizable, contributing to a bias in estimates of survival. Ten of the studies reviewed by EPA reported finding fragmented organisms; others did not quantify evidence of disintegrated organisms. High rates of physical damage and abundant larval fish fragments were reported by Stevens and Finlayson (1978) at the Pittsburg and Contra Costa power plant discharges. Such losses can contribute to a bias (overestimation) of entrainment survival because the number of dead organisms are not properly enumerated. In addition, the low numbers of organisms sampled in the studies in relation to the high annual entrainment numbers give further indication that the sampling effort may not result in an adequate representation of the organisms entrained and therefore the survival estimates may not be representative of what occurs.

Including stunned larvae in the initial survival estimates also results in overestimations of survival, since the majority of these organisms died in the laboratory latent survival studies and even more will die in the natural conditions of the discharge canal because of predation or disrupted growth and development. Twenty-nine studies reviewed included stunned larvae in their initial survival estimates, and only a few of these indicated that this method will overestimate initial survival. The remainder of the studies reviewed did not discuss the treatment of stunned larvae. Many studies reviewed reported only initial acute mortality. Both initial mortality and extended or latent (96 hour) mortality should be studied and reported.

Dead and opaque organisms that may have died before entrainment should not be excluded from the enumeration of dead organisms. Several studies reviewed by EPA noted that dead organisms can turn opaque within an hour.

This is the same amount of time that can elapse during sampling collection and sorting. Also, zero dead and opaque organisms were collected in the samples of one study when the facility was not generating power. Three studies omitted dead and opaque organisms from the dead classification used to estimate survival. This resulted in an elimination of up to 99% of the organisms in the samples of one study. Alternatively, one study counted only those organisms that were opaque as dead.

The study design should support unbiased estimation of survival, taking into account pertinent factors and the changing relative abundances of species and life stages. Because entrainment mortality changes with ambient and operating conditions, and because the numbers of various species and life stages entrained also change diurnally and seasonally, use of an average value for entrainment survival could be misleading. Organisms should be counted and sorted by species, life stage, and size. Entrainment survival should then be calculated separately for each life stage of each species. Entrainment survival estimates appears to vary markedly with fish larval size (EA Engineering, Science, and Technology, 1989); estimates of mortality are often higher for smaller larvae and lower for larger ones. Thus, survival measured for a heterogeneous mixture of sizes will apply only to that mixture under the same conditions, and cannot be used to accurately estimate survival for the species over the course of even part of a season. The approach of modeling survival in relation to size may be more promising (EA Engineering, Science, and Technology, 1989). The implication is that accurate assessment of entrainment survival requires frequent samples throughout a season, to reflect the changing size and species composition of the ichthyoplankton. In most of the studies all data from all samples collected under varied times and conditions were combined to give an average entrainment survival. However, bias could be introduced when a disproportionate number of samples are taken under a specific set of conditions that may not accurately reflect conditions throughout the year. Only 16 of the 37 studies reviewed estimated entrainment survival by sampling reported standard deviations or confidence intervals for the survival estimates. The apparent precision of estimates based on hundreds of organisms, and the estimates themselves, are deceptive. Such estimates are based on aggregated numbers that vary in size; however, larval fish survival is dependent on size (EA Engineering, Science, and Technology, 1989).

The volume of water sampled should always be reported with the number of organisms counted in the sampled volume. This allows estimates of the densities of organisms in the intake and the discharge water. Density estimates provide an important check on assumptions. When organism densities cannot be measured accurately, a useful check on disintegration of organisms that are never counted cannot be performed. Another check on loss of organisms by disintegration is a count of body parts, which was done in only one of the studies reviewed, but this will not account for organisms rendered unidentifiable or disintegrated. In some studies, the numbers of organisms in discharge samples were many times greater than the numbers of organisms in intake samples using the same sampling methods. In other studies, there were many times more organisms collected in the intake samples than in the discharge samples. Such large differences raise concerns about sampling methods and possible sources of bias that would need to be investigated.

Control samples taken to test the mortality associated with sampling gear should be taken as far away from the intake as possible. This will ensure that the rates of mortality determined will be solely from natural causes or sampling damage and not from potential damage due to increased velocity and turbulence near the intake. Sampling mortality should be reduced to the maximum extent possible, using modern sampling techniques (EA Engineering, Science, and Technology, 2000). When control survival is less than discharge survival, no attempts should be made to calculate entrainment survival; this would give an erroneous survival result of greater than 100%. That some studies reported entrainment survival estimates greater than 100% indicates that these studies' methods of calculating entrainment survival were flawed by methodological biases.

Calculating survival from the ratio of the fraction alive in discharge samples to the fraction alive in intake samples requires assumptions not supported by the same studies. These assumptions are that (1) no organisms are lost to counting by destruction in the cooling water system, in other words, the same density of organisms (dead or alive) is observed in the discharge as in the intake; and that (2) the sampling method causes the same rate of mortality in the discharge sample as in the intake sample. The first assumption is without doubt violated for many species and life stages. The second assumption is also questionable, because any organisms alive in the discharge have survived entrainment and may be more resistant to sampling-related mortality. Because the loss of organisms by disintegration is not measured, if a substantial number of organisms are destroyed and thus are not counted in the discharge, it is more likely that entrainment survival will be overestimated. The second assumption can be minimized if methods of sampling are used that reduce sampling mortality to a minimum (EA Engineering, Science, and Technology, 2000); such methods (e.g., rear-draw pumping methods, pumpless flume) were used in only 5 of the 37 studies reviewed. The formula commonly used (EA Engineering, Science, and Technology, 2000) to estimate entrainment survival, $S_I = P_D / P_I$, is appropriate in experimental situations in which the number of organisms at risk is verified to equal the number counted (alive and dead) at the end of the study. It can be applied in observational studies when it is known that the number at risk is conserved (i.e., no organisms are lost in sampling or destroyed so they cannot be counted). The biases that result from loss via sampling or destruction, and other causes, were illustrated by Boreman and Goodyear (1981). If Abbott' s correction for control mortality is applied, it requires the assumption that sampling mortality rate is the same for the intake and discharge samples. This source of bias was also considered by Boreman and Goodyear (1981). Abbott's correction may contribute to overestimation of entrainment survival because it attributes to entrainment only that mortality in excess of the mortality attributed to sampling. This may overestimate entrainment survival for two reasons: it is likely that sampling mortality and entrainment mortality are not entirely additive, and, as noted above, it is quite possible that the sampling mortality rate is less in the discharge sample than in the intake sample used as the control.

A7-5 Applicability of Entrainment Survival Studies to Other Facilities

Because of many factors, any potential for entrainment survival is most likely facility-specific. Therefore, EPA does not suggest that entrainment survival estimates be applied to other facilities, as was done in the Muskingum River Plant study (Ecological Analysts, 1979a). To correctly transfer the results, the physical attributes of facilities would need to be identical. Specifically, the facilities would need to have similar numbers of cooling water flow routes; similar lengths of flow routes in terms of time and linear distance; similar mechanical features in terms of abrasive surfaces, pressure changes, and turbulence; and similar number and types of pumps used. In addition, there would need to be similarity and constancy of the flow rates, transit times, thermal regimes, and biocide regimes. The ecological characteristics of the environment around the facility would also need to be similar in terms of ambient water temperature, dissolved oxygen level, and the species and life stage of organisms present. Similarities or differences in these aspects may profoundly affect the applicability of the study across facilities. The studies reviewed by EPA were unsuitable for developing unbiased estimates of entrainment survival over the pertinent courses of time (diel and seasonal) and the typical environmental and operating conditions at the facilities conducting the studies, and thus cannot be used to estimate entrainment survival at section 316(b) facilities nationwide.

A7-6 Conclusions

EPA's review of the 37 entrainment survival studies revealed a number of limitations that challenge their use in assessing the benefits of section 316(b) regulation of Phase III facilities. The primary issue with regard to these studies is whether their results can support a defensible estimate of survival substantially different from the value of 0% survival assumed by EPA in assessing benefits for the section 316(b) rulemaking. Given that live organisms can be found in the discharge canals of many cooling water intake systems, it may be true that not all organisms are necessarily killed as they pass through the cooling systems of all facilities under all operating conditions. However, the results of the 37 studies, summarized in Table A7-1, suggest that the proportion alive in the samples is highly variable and unpredictable among species and among facilities. The studies document that some species (e.g., herrings, bay anchovy) are very sensitive to entrainment and experience 0% survival with calculated mortality rates of 100% at most facilities. Other species (e.g., striped bass) may be more resistant to entrainment effects. However, even for these apparently hardy species, some studies yielded ranges of entrainment survival estimates that included zero and latent survival values very close to zero. Multiple studies at the same facility (e.g., Bowline Point, Indian Point) yielded survival values for some species (e.g., striped bass) that varied substantially among years, most likely due to a combination of changes in environmental conditions, changes in plant operations, and changes in sampling and testing procedures. The studies indicate that any survival is dependent on temperature, but the effect may vary greatly depending on intake water temperature, plant design, fish species, and life stages. Few of the studies could conclusively document and quantify the specific stressors causing the observed mortalities, and no rigorous, validated method or model was put forward that would allow survival rates to be accurately predicted. Another major constraint on the use of these findings in this rulemaking process is that they cover very few species, and primarily in a single geographical region of the country, thus providing no basis for prediction or projection of effects to other species in other parts of the country. These studies as well as other literature also show that findings from one facility cannot be considered to be valid for another facility, since many site-specific and facility-specific factors may affect the magnitude of mortality that occurs. The current state of knowledge would not support predictions of entrainment survival for the range of species, life stages, regions, and facilities involved in EPA's benefits estimates.

The potential usefulness of the findings of the studies reviewed is further compromised by the numerous factors that can influence the representativeness, accuracy, and precision of the survival estimates presented, and that are often not rigorously accounted for in the studies reviewed. These factors are described in section A7-2, and some of the deficiencies of the studies with regard to these factors are elaborated in section A7-3. The most frequent and serious deficiencies noted (e.g., high control mortalities, omission of fragmented or unidentifiable organisms, and uncertainty regarding post-discharge survival) compromise the accuracy and precision of the survival estimates. In many of the studies reviewed, the precision of the survival estimates was not rigorously assessed, and thus the uncertainty associated with the estimates is not known. If the factors addressed in this review were taken into account in an entrainment survival study, EPA believes that the estimates of survival that would result would not be substantially different from zero.

EPA acknowledges that some of the studies performed at some facilities were designed in a more rigorous manner than others in order to minimize the influence of factors that could compromise findings (e.g., the use of a larval table for assessing physiological condition) and included comprehensive sampling in an attempt to enhance the accuracy and precision of the survival estimates. However, while such studies may have provided estimates for the facility studied under the environmental and operational conditions that occurred at the time the study was performed, these studies do not provide a basis for generalizing specific survival rates for all or even the same species at other facilities or at the same facility in other years. In addition, there exists the possibility of additional post-discharge (latent) mortality when entrained organisms are returned to the receiving waterbody. Overall, the unreliability, variability, and unpredictability of entrainment survival estimates evident from EPA's review of the entrainment survival studies support the use of the assumption of 0% survival in the benefits assessment because there is no clear indication of any defensible estimate of survival substantially different from 0% to use to calculate benefits for section 316(b) regulatory development.

Summary Tables of Entrainment Survival Studies

Anclote Power Plant

Anclote River, FL

1985 Study

CCI Environmental Services, 1996

Sampling: Dates: Sept. 25-29, October 9-11, and November 1-2
Samples collection frequency: a few days per month
Times of peak abundance: autumn months when densities maybe not the highest
Time: mostly at night, some late afternoon to evening
Number of replicates: varied between 5-25 per month
Intake and discharge sampling: paired number, timing unknown
Elapsed collection time: 20-30 minutes
Method: 400 µm mesh net with 1 m diameter and 5 gallon plastic bucket with 500 µm mesh side panels
Depth: mid-depth and surface
Intake location: unknown
Discharge location: condenser discharge and point of discharge in canal
Water quality parameters measured: pH, DO, salinity
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: operated at peak load to maximize.T, 1-2 Units
Number of pumps in operation: varied due to sampling location, 0-4 pumps
Temperature: Discharge temperature: 28.8-38.3 °C
    ΔT average: 5.4-7.3 °C
Biocide use was not noted

Survival Estimation:
Number of sampling events: 8
Total number of samples collected: 120
Total number of organisms collected: 41,196
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: approx. equal
Most abundant species: not classified to species level
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars for 24 hours
    In several replicates, more organisms were counted after 24 hours in jar
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 64% for fish larvae; 73% for Amphipoda
    44% for Chaetognatha; 72% for crab larvae
    72% for Caridean shrimp
Initial discharge survival range: 8-47% for fish larvae; 29-58% for Amphipoda
    28-35% for Chaetognatha; 74-80% for crab larvae
    45-66% for Caridean shrimp
Calculation of Entrainment Survival: Discharge survival / Intake survival
Mean survival for each replicate was reported as survival estimate per species
Confidence intervals (95%) and standard deviations were calculated
Significant differences were tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: none collected
Larval survival: decreased markedly within hours of collection
Raw data: were provided to verify results
Temperature effects: unknown
Mechanical effects: unknown
Quality control: QA/QC officer oversaw sorting and sample handling
Peer review: not mentioned, study was conducted for the facility

Bergum Power Station

Bergumermeer, Netherlands

1976 Study

Hadderingh, 1978

Sampling: Dates: April 27-June 1
  Samples collection frequency: approximately once per week
  Times of peak abundance: coincided with abundance of larvae and juveniles
  Time: unknown
  Number of replicates: unknown
  Intake and discharge sampling: unclear if paired sampling
  Elapsed collection time: 3 minutes
  Method: conical net with 0.5 mm mesh and 0.5 m diameter
  Depth: unknown
  Intake location: unknown
  Discharge location: in outlet before weir
  Water quality parameters measured: none
  DOC and POC measured: no
  Intake and discharge velocity: 40 cm/sec

Operating Conditions During Sampling:
  Number of units in operation: unknown
  Number of pumps in operation: unknown
  Temperature: Intake temperature: 10.8-21.6
    Discharge temperature: 16.7-24.6 °C
    ΔT ranged from 2.4-8.0 °C
  Biocide use was not noted

Survival Estimation:
  Number of sampling events: 6
  Total number of samples collected: unknown
  Total number of organisms collected: unknown at intake, 1,148 at discharge
  Number of organisms entrained per year: unknown
    approximately 10 million organisms entrained per day in May
  Fragmented organisms: not discussed
  Equal number of organisms collected at intake and discharge: unknown
  Most abundant species: smelt, perches
  Stunned larvae: unknown if included in survival proportion
  Dead and opaque organisms: not discussed
  Latent survival: observed in floating buckets in the outlet canal for 24 hours
    5-50% appeared to be dead in buckets floating in outlet canal
    However, latent survival was not explicitly studied
  Data: survival by sampling date and then averaged
  Controls: survival in the intake samples was considered to be the control
  Initial intake survival range: 54-100% for smelt
    81-96% for perches
  Initial discharge survival range: 10-28% for smelt
    32-74% for perches
  Calculation of Entrainment Survival: Discharge survival / Intake survival
  Confidence intervals and standard deviations were not presented.
  Significant differences were not tested between the intake and discharge survival
  Survival calculated for species with fewer than 100 organisms collected: yes
  Egg survival: no eggs collected
  Larval survival: increased in samples later in year, may be due to larger sized
  Raw data: were not provided to verify results
  Temperature effects: not discussed
  Mechanical effects: not discussed
  Quality control: not discussed
  Peer review: work done for facility, published in *Applied Limnology*

Bowline Point Generating Station

Hudson River, NY

1975 Study

Ecological Analysts, 1976a

Sampling: Dates: June 3-July date unknown
Samples collection frequency: 1-4 times per week
Times of peak abundance: sampling intended to coincide with peak densities
Time: day or night
Number of replicates: unknown
Intake and discharge sampling: unknown if paired
Elapsed collection time: 15 minutes
Method: larval collection tables
Depth: unknown
Intake location: in front of intake
Discharge location: from standpipe connected to discharge pipe of Unit 2
Water quality parameters measured: conductivity, DO, pH
DOC and POC measured: no
Intake and discharge velocity: intake: 1.5-2 m/sec, discharge 2-4.6 m/sec

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: ΔT range: 0.5-12.1 °C
Biocide use was not noted

Survival Estimation:
Number of sampling events: 37
Total number of samples collected: 400
Total number of organisms collected: 4,643
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: no, more at intake
Higher percentage of larvae were collected at the discharge station in the later weeks of the collection period. Conversely, a higher percentage of larvae were collected at the intake at the beginning weeks of the collection period. This discrepancy in larval collection combined with higher survival rates later in the spawning season accounts for the bias which results in higher survival rates at the discharge station. The study acknowledges this bias and concludes that it is responsible for the higher discharge survival estimates.
Most abundant species: striped bass, white perch and bay anchovy
Stunned larvae: included in initial survival proportion; most died within hours
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars for 96 hours
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 81% for striped bass
56% for white perch
9% for bay anchovy
Initial discharge survival range: 74% for striped bass
68% for white perch
2% for bay anchovy
Calculation of Entrainment Survival: Discharge survival / Intake survival
Confidence intervals (95%) were presented
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: no
Egg survival: not studied
Larval survival: decreased markedly within 3 hours of collection.
Raw data: were not provided to verify results
Temperature effects: too few samples collected to establish relationship
Mechanical effects: extent was not discussed
Quality control: color coded labeling, routine checks on sorting accuracy
Peer review: not mentioned, study was conducted for the facility

Bowline Point Generating Station

Hudson River, NY

1976 Study

Ecological Analysts, 1977

Sampling: Dates: May 18-July 26

- Samples collection frequency: approx. 4 nights per week
- Times of peak abundance: for all species except Atlantic tomcod
- Time: at night
- Number of replicates: stated average of 10 per sampling trip
- Intake and discharge sampling: sorted simultaneously
- Elapsed collection time: 15 minutes
- Method: larval collection table with 4 inch diameter trash pump
- Depth: unknown
- Intake location: in front of Unit 1 trash racks
- Discharge location: from standpipes of discharge at Units 1 or 2
- Water quality parameters measured: conductivity, pH, and DO
- DOC and POC measured: no
- Intake and discharge velocity: intake: 0.11-3 m/sec, discharge: 3-4.6 m/sec

Operating Conditions During Sampling:

- Number of units in operation: varied between 1 and 2
- Number of pumps in operation: unknown
- Temperature: discharge range: 29.0-35.9 °C
- Biocide use was not noted

Survival Estimation:

- Number of sampling events: 39
- Total number of samples collected: 688
- Total number of organisms collected: 2,795
- Number of organisms entrained per year: unknown
- Fragmented organisms: only included in count if >50% was present
- Equal number of organisms collected at intake and discharge: no, very different
- Most abundant species: striped bass, white perch, atlantic tomcod, bay anchovy, herrings
- Stunned larvae: included in initial survival proportion
- Dead and opaque organisms: not discussed
- Latent survival: observed in aerated glass jars for 96 hours
- Data: was summarized and averaged over the entire sampling period
- Controls: survival in the intake samples was considered to be the control
- Initial intake survival range: 81-90% for striped bass
    - 62% for white perch
    - 54-82% for Atlantic tomcod
    - 7-53% for bay anchovy
    - 35% for herrings
- Initial discharge survival range: 0-54% for striped bass
    - 0-33% for white perch
    - 29-94% for Atlantic tomcod
    - 0-10% for bay anchovy
    - 20% for herrings
- Calculation of Entrainment Survival: Discharge survival / intake survival
- Confidence intervals (95%) were presented
- Significant differences were not tested between the intake and discharge survival
- Survival calculated for species with fewer than 100 organisms collected: yes
- Egg survival: not studied
- Larval survival: decreased markedly within 12 hours of collection.
- Raw data: were not provided to verify results.
- Temperature effects: trend of decreasing survival when temperatures >30 °C
- Mechanical effects: unknown extent
- Quality control: color coded labels, immediate checks of sorted samples, SOPs
- Peer review: not mentioned, study was conducted for the facility

Bowline Point Generating Station

Hudson River, NY

1977 Study

Ecological Analysts, 1978a

Sampling: Dates: March 7-July 15
Samples collection frequency: 5 nights per week
Times of peak abundance: covered of peak densities of most targeted species
Time: at night
Number of replicates: varied between 2 and 10 per site
Intake and discharge sampling: paired
Elapsed collection time: 15 minutes
Method: larval table with pump, 2 pumps at intake; 2 tables at discharge
ambient water injection system added to reduce prolonged temp. exposure
Depth: middle to bottom at intake, at standpipes for discharge
Intake location: in front of Unit 1 trash rack
Discharge location from standpipes of either Unit 1 or 2, depending on operation
Water quality parameters measured: conductivity, pH and DO
DOC and POC measured: no
Intake and discharge velocity: intake: 0.11-2 m/sec; discharge 3-4.6 m/sec

Operating Conditions During Sampling:
Number of units in operation: varied between 1 and 2
Number of pumps in operation: 2 pumps throttled or 2 pumps full
Temperature: Intake range: 3.7-27 °C
ΔT range: not provided
Biocide use was not noted

Survival Estimation:
Number of sampling events: 46
Total number of samples collected: 736
Total number of organisms collected: 4,071
Number of organisms entrained per year: unknown
Fragmented organisms: included in count if >50% of organism was present
Equal number of organisms collected at intake and discharge: no, very different
Most abundant species: striped bass, white perch, bay anchovy, herrings and silversides
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars for 96 hours
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 74% for striped bass
69% for white perch
0-16% for bay anchovy
54% for herrings
37% for silversides
Initial discharge survival range: 71-72% for striped bass
34% for white perch
0-2% for bay anchovy
23% for herrings
16% for silversides
Calculation of Entrainment Survival: Discharge survival / Intake survival
Standard errors were presented
Significant differences were tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not studied
Larval survival: survival increased with larval length
Raw data: were not provided to verify results.
Temperature effects: decreased survival >33 °C
Mechanical effects: unknown
Quality control: color coded labels, checks of sorting efficiency
Peer review: not mentioned, study was conducted for the facility

Bowline Point Generating Station

Hudson River, NY

1978 Study

Ecological Analysts, 1979b

Sampling: Dates: March 13-October 16
Samples collection frequency: 1-5 times per week
Times of peak abundance: majority of samples in June and July
Time: at night
Number of replicates: varied between 1-10 per sampling date.
Intake and discharge sampling: mostly paired, not all sites sampled all dates
Elapsed collection time: 15 minutes
Method: pump/larval table combination; also floating larval table
Depth: at bottom for intake and unspecified for discharge
Intake location: in front of trash racks of Unit 1 or 2
Discharge location: at either Unit 1 or 2 in standpipes from discharge pipe floating larval table used for sampling at point of discharge
Water quality parameters measured: salinity, pH, DO, conductivity
DOC and POC measured: no
Intake and discharge velocity: intake: 0.15-0.23 m/s

Operating Conditions During Sampling:
Number of units in operation: varied between 1 and 2
Number of pumps in operation: unknown
Temperature: unknown
Biocide use was not noted

Survival Estimation:
Number of sampling events: 40
Total number of samples collected: 609
Total number of organisms collected: unknown
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: varied
Most abundant species: striped bass, bay anchovy, white perch and herrings
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in holding jars for 96 hours
Data: was summarized and averaged over the entire sampling period.
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 48-49% for striped bass
  39% for white perch
  4% for bay anchovy
  19% for herrings
Initial discharge survival range: 51-63% for striped bass
  19% for white perch
  0% for bay anchovy
  23% for herrings
Calculation of Entrainment Survival: Discharge survival / Intake survival
Standard error were presented
Significant differences were tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not studied
Larval survival: decreased markedly within 12 hours of collection
  Survival increased with larval length
Raw data: were not provided to verify results
Temperature effects: no survival for YSL for any species at temps. >30 °C
  no survival for PYSL for any species at temps. >33 °C
  majority of samples collected at temperatures <30 °C
Mechanical effects: recirculation of water occurs
Quality control: color coded labels, double checks, sorting efficiency checks
Peer review: not mentioned, study was conducted for the facility

Bowline Point Generating Station

Hudson River, NY

1979 Study

Ecological Analysts, 1981a

Sampling: Dates: May 23-June 27
Samples collection frequency: 3-5 days per week
Times of peak abundance: timed to coincide with peak densities
Time: 1400 to 2200 hours
Number of replicates: varied between 0-9 per sampling date, generally 7
Intake and discharge sampling: mostly paired, initiated simultaneously
Elapsed collection time: 15 minutes
Method: intake: floating larval table or rear draw sampling flume discharge: pumpless plankton sampling flume or pumped larval table
Depth: intake: mid-depth (4.6 m); discharge: 2 m below surface
Intake location: in front of trash racks
Discharge location: at standpipe and diffuser
Water quality parameters measured: conductivity, pH, DO
DOC and POC measured: no
Intake and discharge velocity: intake: 1.5-3.0 m/sec; discharge 3-4.6m/sec

Operating Conditions During Sampling:
Number of units in operation: varied, power generated on only 5 sampling dates
Number of pumps in operation: operated through sampling
Temperature: ΔT range: not provided
Biocide use was not noted

Survival Estimation:
Number of sampling events: 19
Total number of samples collected: 435
Total number of organisms collected: 1,212
Number of organisms entrained per year: estimated 1.5 million striped bass 2.7 million white perch
Fragmented organisms: included in count if 50% of organism was present
Equal number of organisms collected at intake and discharge: approx. equal
Most abundant species: white perch, bay anchovy, striped bass, herrings
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars for 96 hours.
Data: was summarized and averaged over the entire sampling period.
Controls: Survival in the intake samples was considered to be the control.
Initial intake survival range: 63-71% for striped bass; 39-63% for white perch 4-14% for bay anchovy; 56-61% for herrings
Initial discharge survival range: 35-41% for striped bass; 26-35% for white perch 0-4% for bay anchovy; 30-31% for herrings
Calculation of Entrainment Survival: Discharge survival / Intake survival
Standard errors were presented.
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: determined by translucency and hatching success
Larval survival: decreased markedly within 12 hours of collection.
Raw data: were not provided to verify results.
Temperature effects: little survival at discharge temperatures >30 °C
Mechanical effects: due to no power generation on the majority of sampling dates, results give indication of extent of mechanical induced mortality
This study included analysis of diel patterns of ichthyoplankton abundance in comparison to diel patterns of plant generation. Facility tends to operate at 85 to 95% of capacity in the mid-afternoon hours which results in higher ΔT's and discharge temperatures. Facility tends to operate at minimum level, 20 to 30% capacity, in early morning when larval abundance is high and entrainment survival samples collected. Sample collection during the hours when the facility is operating at minimum levels of percent capacity, and at times with correspondingly lower ΔT's and discharge temperatures, may add bias to the results since more organisms will be exposed to lower levels of temperature stress. The peak abundance for each species is only slightly higher than abundance throughout the day. Thus, collectively, more organisms may be exposed to higher temperatures and have higher mortality rates but are not reflected in samples collected at night.
Quality control: color coded labels, check of sorting efficiency, SOPs
Peer review: not mentioned, study was conducted for the facility

Braidwood Nuclear Station

Kankakee River, IL

1988 Study

EA Science and Technology, 1990

Sampling: Dates: June 1-July 5
- Samples collection frequency: 3 samples taken in 35 days
- Times of peak abundance: peak densities of eggs and larvae were found in May
- Time: varied; day and night at intake, only day at discharge
- Number of replicates: varied, 8-14 per sampling date
- Intake and discharge sampling: more discharge replicates, not always same day
- Elapsed collection time: 2 minutes
- Method: plankton net with 1.0 m opening, net rinsed out in bucket
- Depth: unknown
- Intake location: in holding pond into which river water was pumped
- Discharge location: downstream of outfall in discharge canal
- Water quality parameters measured: none
- DOC and POC measured: no
- Intake and discharge velocity: 0.4-0.6 ft/sec

Operating Conditions During Sampling:
- Number of units in operation: unknown
- Number of pumps in operation: unknown
- Temperature: not given
- Biocide use was not noted

Survival Estimation:
- Number of sampling events: 3
- Total number of samples collected: 62
- Total number of organisms collected: 294
- Samples, which were collected after peak densities, contained fewer and larger organism which may in turn have higher survival rates.
- Number of organisms entrained per year: estimate 5.8-11.2 million eggs/larvae
- Fragmented organisms: not discussed
- Equal number of organisms collected at intake and discharge: more at intake
- Most abundant species: minnows and sunfish
- Stunned larvae: included in survival proportion
- Dead and opaque organisms: were omitted from all calculations of survival
- Thus 67% of those dead in the intake samples and 21% of those dead in the discharge samples were omitted from the survival proportions
- Latent survival: not studied
- Data: was summarized and averaged over the entire sampling period
- Controls: survival in the intake samples was considered to be the control.
- Initial intake survival range: 60% for minnows (17% including dead-opaque)
  78% for sunfish (54% including dead-opaque)
- Initial discharge survival range: no minnows collected
  80% for sunfish (76% including dead-opaque)
- Calculation of Entrainment Survival: Discharge survival / Intake survival
- Survival proportions calculated by dividing number of live larvae by number of live plus dead-transparent larvae
- Confidence intervals / standard deviations: were not presented.
- Significant differences were not tested between the intake and discharge survival
- Survival calculated for species with fewer than 100 organisms collected: yes
- Egg survival: data not given
- Larval survival: not studied
- Raw data: were not provided to verify results.
- Temperature effects: not studied
- Mechanical effects: not studied
- Quality control: not discussed
- Peer review: not mentioned, study was conducted for the facility

.

Brayton Point

Mount Hope Bay, MA

1997-1998 Study

Lawler, Matusky & Skelly Engineers, 1999

Sampling: Dates: April 30-August 27, 1997 and February 26-July 29, 1998
Samples collection frequency: weekly
Times of peak abundance: not discussed specifically
Time: varied, day or night
Number of replicates: varied between 14 and 77
Intake and discharge sampling: not paired, 2 tables located in discharge canal
Elapsed collection time: 15 minutes
Method: pump/larval table combination
Depth: mid-depth for intake, 2-4 m below surface at discharge
Intake location: directly in front of Unit 3 intake screens
Discharge location: middle of discharge canal or from Unit 4 discharge pipe
Water quality parameters measured: conductance and salinity periodically
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: intake range: 4.5-28.0 °C
discharge range: 11-45 °C
ΔT data not provided
Biocide use: samples collected when not in use

Survival Estimation:
Number of sampling events: 41
Total number of samples collected: 2692 in 1997; 4137 in 1998
Total number of organisms collected: 2,256 in intake; 27,574 in discharge
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal no. of organisms collected at intake and discharge: 4-79X more in discharge
Most abundant species: bay anchovy, American sand lance
Stunned larvae: assumed stunned larvae did not survive due to increased predation risk
Dead and opaque organisms: not discussed
Latent survival: observed in holding cups in aquarium racks for 96 hours
Data: was summarized and averaged with both sampling years combined
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 0% for American sand lance
4% for tautog
0% for bay anchovy
44-46% for windowpane flounder
32% for winter flounder
Initial discharge survival range: 0% for American sand lance
4% for tautog
0% for bay anchovy
29-30% for windowpane flounder
33-38% for winter flounder
Calculation of Entrainment Survival: discharge survival / intake survival
Standard errors were presented
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not studied
Larval survival: survival increased with larval length, decreased markedly within 4 hours of holding in latent studies
Raw data: were provided by species and not by sample to verify results
Temperature effects: survival decrease markedly at temps >20 °C
Mechanical effects: unknown extent
Quality control: continuous sampling plan which included reanalysis of samples
Peer review: not mentioned, study was conducted for the facility

Cayuga Generating Plant

Wabash River, IN

1979 Study

Ecological Analysts, 1980a

Sampling: Dates: May 17-31 and June 8-22
Samples collection frequency: daily
Times of peak abundance: highest average densities sampled were June 8-10
Time: 1900 to 0300 hours
Number of replicates: varied between 0-6 per sampling date.
Intake and discharge sampling: simultaneous sampling, transit time = 36 mins
Elapsed collection time: 15 minutes
Method: pump / larval table collection system
Depth: intake: 2 and 5 m below surface, discharge: 3-4 m below surface
Intake location: in front of intake structure
Discharge location: where discharge of Units 1 and 2 enter canal
also cooling tower discharge in discharge canal
Water quality parameters measured: DO
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: varied, 2-4
Temperature: intake range: 17.6-24.3 °C
discharge range: 29.4-33.3 °C
ΔT ranged from 8.4-11.8 °C
Biocide use: occurs daily, but ceased at least 2 hours before sampling

Survival Estimation:
Number of sampling events: 24
Total number of samples collected: 80
Total number of organisms collected: 2,556
Number of organisms entrained per year: unknown
Fragmented organisms: 13-14.6% were damaged
Equal number of organisms collected at intake and discharge: more at intake
Most abundant species: suckers, perches, carps, temperate basses
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: 48 hour observation in aerated glass jars of filtered river water
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 86-98% for suckers
28-92% for carps and minnows
50-86% for perches
Initial discharge survival range: 75-92% for suckers
12-74% for carps and minnows
43-69% for perches
Calculation of Entrainment Survival: Discharge survival/ Intake survival
Confidence intervals: were not presented; standard errors were calculated standard error sometime as high as survival
Significant differences were tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not studied
Larval survival: latent effects were not seen until 48 hours after collection
Raw data: were provided to verify results
Temperature effects: lower survival for all species at temperatures above 30 °C
Mechanical effects: survival decreased when number of pumps increased
Quality control: sorting efficiency checks and color coded labels
Peer review: not mentioned, study was conducted for the facility

Connecticut Yankee Atomic Power Company

Connecticut River, CT

1970 Study

Marcy, 1971

Sampling: Dates: June 30-July 29
Samples collection frequency: weekly
Times of peak abundance: sampling dates were estimated times of peak larvae
Time: varied throughout day to avoid biocide application
Number of replicates: sampled in triplicate, data from replicates combined
Intake and discharge sampling: samples taken successively not all sites sampled on all dates
Elapsed collection time: 5 minutes
Method: conical nylon plankton net with 1 L plastic bucket attached to cod end portable water table for maintaining temperature during counting
Depth: median depth at intake; surface, middle and bottom of discharge because dead fish in canal may sink or float due to immobility or changes in specific gravity of water, thus giving inconsistent results
Intake location: unknown
Discharge location: outfall weir and 3 location in discharge canal
Water quality parameters measured: DO
DOC and POC measured: no
Intake and discharge velocity: 1-2 ft/sec, may approach 8 ft/sec

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: Discharge temperature: 28.2-41 °C
ΔT ranged from 6-12.1 °C
Biocide use: sampling avoided daily application of 13% sodium hydrochlorite

Survival Estimation:
Number of sampling events: 7
Total number of samples collected: 102
Total number of organisms collected: 2,681
Number of organisms entrained per year: unknown
Fragmented organisms: majority of dead fish were mangled
Equal number of organisms collected at intake and discharge: unknown
Most abundant species: alewife and blueback herring
Stunned larvae: not discussed
Dead and opaque organisms: not discussed
Latent survival: not studied
Data: all data for all species combined, survival calculated for each date
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 29-100% for all species combined
Initial discharge survival range: 0-7.5% for all species combined
Calculation of Entrainment Survival: number live per cubic meter in each discharge sample/ number live per cubic meter in intake for each day
Confidence intervals and standard deviations: were not presented
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: July 29
Egg survival: not sampled
Larval survival: no organisms were found alive at end of discharge canal at temperatures >30 °C
Raw data: were not provided to verify results
Temperature effects: at discharge temp. >33.5 °C, no living organisms sampled
Mechanical effects: not discussed
Quality control: not discussed
Peer review: published in notes of Journal Fisheries Research Board of Canada

Connecticut Yankee Atomic Power Company

Connecticut River, CT

1971-1972 Study

Marcy, 1973

Sampling: Dates: June 2-24, 1971 and June 27-July 13, 1972 (mechanical only)
Samples collection frequency: approximately once per week
Times of peak abundance: unknown
Time: afternoons and evenings
Number of replicates: three at each station although at three different depths data were combined for each station
Intake and discharge sampling: collected successively at the 5 sites
Elapsed collection time: 5 minutes
Method: conical nylon plankton net with 0.39 mm mesh and 1L plastic bucket
Depth: surface, middle, and bottom
Intake location: unknown
Discharge location: below weir and 3 points along discharge canal
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: 0.3-0.6 m/sec, may approach 2.4 m/sec

Operating Conditions During Sampling:
Number of units in operation: unknown in 1971, no power generation in 1972
Number of pumps in operation: unknown
Temperature: Intake temperature: 16-26 °C (1971); 19.9-28 °C (1972)
Discharge temperature: 29-35 °C (1971 only)
ΔT ranged from 9-13 °C (1971 only)
Biocide use: 1972 study, chemical mortality indistinguishable from mechanical

Survival Estimation:
Number of sampling events: 2 (1971) and 7 (1972)
Total number of samples collected: 30 (1971) and 246 (1972) often 2-3 times as many samples collected at discharge
Total number of organisms collected: 1,068 (1971) and 10,271 (1972)
Number of organisms entrained per year: unknown, estimated entrainment is 1.7-5.8% of nonscreenable fish which pass facility
Fragmented organisms: not discussed
Equal no. of organisms collected at intake and discharge: 4X more in discharge lower numbers collected at end of canal may be due to dead fish settling out of water column
Most abundant species: alewife and blueback herring
Stunned larvae: were included as live unless they had begun to turn opaque
Dead and opaque organisms: only opaque organisms were counted as dead
Latent survival: not studied
Data: replicate data combined; survival calculated per sampling day
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 64-100% for all species sampled (1971)
Initial discharge survival range: 0% for all species sampled (1971)
Calculation of Entrainment Survival: number live per cubic meter in each discharge sample/ number live per cubic meter in intake for each day
Confidence intervals and standard deviations were not presented.
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: none sampled
Larval survival: no survival anywhere in discharge at temperatures >29 °C
Raw data: were not provided to verify results
Temperature effects: organisms exposed to elevated temp. for 50-100 min estimated as causing 20% of mortality most fish are dead at the end of the 1.14 mile canal
Mechanical effects: 1972 study indicated that 72-87% is mechanical mortality
Quality control: not discussed
Peer review: published in Journal Fisheries Research Board of Canada

Contra Costa Power Plant

San Joaquin River, CA

1976 Study

Stevens and Finlayson, 1978

Sampling: Dates: April 28-July 10
Samples collection frequency: once per week
Times of peak abundance: unknown
Time: varied, about 25% of all samples collected at night
Number of replicates: typically 3
Intake and discharge sampling: paired at closest time and temperature
Elapsed collection time: 1-2 minutes
Method: 505 micron mech conical nylon plankton net with 0.58 m plastic collecting tubes on cod end; towed net on boat at 0.6 ft/sec
Depth: mid-depth
Intake location: at intake for units 6 and 7
Discharge location: at discharge for units 1-5 and units 6-7
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: Intake temperature: 19-30 °C
Discharge temperature 19-38 °C
Biocide use was not noted

Survival Estimation:
Number of sampling events: 6
Total number of samples collected: unknown
Total number of organisms collected: 966 (1,606 at north shore control)
Number of organisms entrained per year: unknown
Fragmented organisms: enumerated in one replicate tow higher proportion of unidentifiable fragments in discharge
Equal number of organisms collected at intake and discharge: more at intake
Most abundant species: striped bass
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: not studied
Data: was summarized by mean larval length
Controls: survival in the intake samples was considered to be the control additional control on north shore to determine background mortality control site at north shore away from intake had lower mortality rates
Initial intake survival range: 33-90% for striped bass
recirculated water may be cause of some intake mortality
Initial discharge survival range: 0-50% for striped bass
Calculation of Entrainment Survival: paired discharge survival divided by paired intake survival
Confidence intervals and standard deviations were not presented.
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not studied
Larval survival: increased survival with greater larval length
Raw data: were not provided to verify results
Temperature effects: mortality increased with increase in discharge temperature higher mortality with discharge temp. >31 and ΔT >7 °C linear regression showed that half died at temps >33.3 °C
0% survival at temperatures of 38 °C
Mechanical effects: stated not as much of an effects as temperature
Quality control: not discussed
Peer review: study conducted by California Fish and Game with funds provided by facility

Danskammer Point Generating Station

Hudson River, NY

1975 Study

Ecological Analysts, 1976b

Sampling: Dates: May 29-November 18
Samples collection frequency: varied from once every 2 weeks to 4 times per week
Times of peak abundance: increased frequency during spawning
Time: varied, generally overnight
Number of replicates: varied, ranged from 1 to 12
Intake and discharge sampling: usually paired
Elapsed collection time: unknown
Method: pump/larval table
Depth: mid-depth for intake, unspecified for discharge
Intake location: in canal in front of traveling screens
Discharge location: outlet of Unit 3 to Hudson River
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: varied between 1 and 2
Temperature: Intake temperature range: 21-26 °C
Discharge temperature range: not provided
ΔT ranged from 0-10 °C
Biocide use not used during sampling; noted that chlorination will reduce survival

Survival Estimation:
Number of sampling events: 29
Total number of samples collected: 372
Total number of organisms collected: 1,655
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal no. of organisms collected at intake / discharge: up to 2X more in discharge
Most abundant species: herrings, striped bass and white perch
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars for 96 hours
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 0-50% for striped bass
33-100% for white perch
63-100% for herrings
Initial discharge survival range: 0-39% for striped bass
38-80% for white perch
20-22% for herrings
Calculation of Entrainment Survival: Discharge survival / Intake survival
Confidence intervals and standard deviations: were not presented.
Significant differences were tested between the intake and discharge survival
Significantly lower survival in discharge: herring PYSL
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: none collected
Larval survival: decreased markedly within 3 hours of collection.
Raw data: were not provided to verify results
Temperature effects: significantly lower survival when ΔT >10 °C and discharge temperature >30 °C
Mechanical effects: not discussed
Quality control: samples double checked and data entry monitored
Peer review: not mentioned, study was conducted for the facility

Fort Calhoun Nuclear Station

Missouri River, NE

1973-1977 study

Carter, 1978

Sampling: Dates: October 1973-June 1977
Samples collection frequency: 5-24 times per year
Times of peak abundance: same frequency all year round
Time: unknown
Number of replicates: unknown
Intake and discharge sampling: unknown if timing was paired
Elapsed collection time: unknown
Method: plankton net with 571 μm mesh and 0.75 m diameter
Depth: unknown
Intake location: in river near intake
Discharge location: near discharge in river immediately downstream of intake
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: varied, 25-97% of full power or shut down
Number of pumps in operation: unknown
Temperature: Discharge temperature: 27.0-36.9 °C during summer samples
  ΔT ranged from 0.6-13.5 °C
Biocide use: unspecified number of samples collected during chlorination

Survival Estimation:
Number of sampling events: 89 (16 when facility was shut down)
Total number of samples collected: unknown
Total number of organisms collected: 24,535 macroinvertebrates
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: no, varied
Most abundant species: Ephemeroptera, Hydropsychidae, Chironomidae
Stunned larvae: macroinvertebrates studied
Dead and opaque organisms: not discussed
Latent survival: not studied
Data: was summarized and averaged over entire sampling period
Controls: Survival in the intake samples was considered to be the control
Initial intake survival range: 12-26% for Ephemeroptera
  42-51% for Hydropsychidae
  35-60% for Chironomidae
Initial discharge survival range: 18-32% for Ephemeroptera
  47-56% for Hydropsychidae
  43-66% for Chironomidae
Calculation of Entrainment Survival: Average differential mortality
Confidence intervals / standard deviations: were calculated but not presented
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not collected
Larval survival: macroinvertebrates only were studied
Raw data: were not provided to verify results
Temperature effects: discussed but data not presented
Mechanical effects: studied during 16 dates when facility was shut down
Quality control: unknown
Peer review: not mentioned, study was conducted for the facility

Ginna Generating Station

Lake Ontario, NY

1980 Study

Ecological Analysts, 1981c

Sampling: Dates: June 11-24 and August 8-21

- Samples collection frequency: 5 times per week
- Times of peak abundance: to coincide with peak densities of targeted species
- Time: late afternoon or early evening
- Number of replicates: unknown
- Intake and discharge sampling: simultaneous sampling at both sites
- Elapsed collection time: 15 minutes
- Method: Intake: pump to floating rear-draw sampling flume
  - Discharge: floating rear-draw pumpless plankton sampling flume
  - Also used ambient water injection to reduce exposure to high temps.
- Depth: unknown
- Intake location: at screenhouse intake after flow through 3,100 ft intake tunnel
- Discharge location: discharge canal
- Water quality parameters measured: none
- DOC and POC measured: no
- Intake and discharge velocity: unknown

Operating Conditions During Sampling:

- Number of units in operation: unknown
- Number of pumps in operation: unknown
- Temperature: Discharge range: 18.5-34.4 °C
  - ΔT ranged from 8-10 °C
- Biocide use: sampled 4 hours after routine injections

Survival Estimation:

- Number of sampling events: 20
- Total number of samples collected: 255
- Total number of organisms collected: 664
- Number of organisms entrained per year: unknown
- Fragmented organisms: not discussed
- Equal number of organisms collected at intake and discharge: varied
- Most abundant species: alewife
- Stunned larvae: included in initial survival proportion
- Dead and opaque organisms: not discussed
- Latent survival: observed in aerated glass jars of filtered water for 48 hours
- Data: was summarized and averaged over the sampling month
- Controls: survival in the intake samples was considered to be the control
- Initial intake survival range: 16.3% for alewife eggs
  - 39% for alewife larvae
  - 58-71% for rainbow smelt
- Initial discharge survival range: 62.5% for alewife eggs; 16% hatching success
  - 0% for Alewife larvae
  - 0% for rainbow smelt
- Calculation of Entrainment Survival: Discharge survival/Intake survival
- In June, only one larvae was found alive in the discharge samples
- Standard errors were presented
- Significant differences were tested between the intake and discharge survival
- Survival calculated for species with fewer than 100 organisms collected: yes
- Too few of many species were collected at the two sites (only 1 or 2 per site) to provide any reliable estimate of entrainment survival
- Egg survival: determined by translucency and hatching success
- Raw data: were provided to verify results
- Temperature effects: none survived at any temperature
- Mechanical effects: none survived at any temperature
- Quality control: SOPs, color coded labels, sorting efficiency checks
- Peer review: not mentioned, study was conducted for the facility

Indian Point Generating Station

Hudson River, NY

1977 Study

Ecological Analysts, 1978c

Sampling: Dates: Jun 1-July 15

Samples collection frequency: twice per week
Times of peak abundance: expected to coincide with peak densities
Time: 1800-0200 hours
Number of replicates: varied between 5-7 per sampling date.
Intake and discharge sampling:
Elapsed collection time: 15 minutes
Method: pump/larval table with ambient water injection to reduce temp. stress
Depth: unknown
Intake location: at intake of Units 2 and 3
Discharge location: discharge for Unit 3 and discharge common to all Units
Water quality parameters measured: DO, pH and conductivity
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:

Number of units in operation: varied between 2 and 3, outage at Unit 2 from 7/4
Number of pumps in operation: 6, at or near full capacity
Temperature: Intake range: 18.8-26.4 °C
  Discharge range: 22.7-34.9 °C
  ΔT during study not provided
Biocide use: unknown

Survival Estimation:

Number of sampling events: 7
Total number of samples collected: unknown
Total number of organisms collected: 4,097
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed specifically, however, there were 115 Morone spp. organisms which could not be further identified to the species level and there were 55 organisms which were mutilated to the point of being unidentifiable to even the family level of organization. Entrainment survival may have been even lower if these mutilated samples were included in the assessment.
Equal number of organisms collected at intake and discharge: more at intake
Most abundant species: striped bass, white perch, bay anchovy and herrings
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: in aerated holding container in ambient water bath for 96 hours
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 0-11% for bay anchovy; 60-77% striped bass
  66% for white perch; 36% for herrings
Initial discharge survival range: 3% for bay anchovy; 29-45% for striped bass
  15% for white perch; 11% for herrings
Calculation of Entrainment Survival: Discharge survival / Intake survival
Standard errors were presented
Significant differences were tested between the intake and discharge survival
Significantly lower survival in discharge: striped bass YSL and PYSL
  white perch PYSL
  bay anchovy PYSL
  herring PYSL
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not studied
Raw data: were not provided to verify results
Temperature effects: no determination that temperature had a significant effect
Mechanical effects: unknown
Quality control: color coded labels and immediate checks of sorted samples
Peer review: not mentioned, study was conducted for the facility

Indian Point Generating Station

Hudson River, NY

1978 Study

Ecological Analysts, 1979c

Sampling: Dates: May 1-July 12

- Samples collection frequency: 2 consecutive days per week
- Times of peak abundance: coincided with spawning of targeted species
- Time: 1800-0200 hours
- Number of replicates: approximately 6 per date
- Intake and discharge sampling: simultaneous
- Elapsed collection time: 15 minutes
- Method: pump/ larval table with ambient water injection
- Depth: 1-3 m below surface, approximately mid-depth
- Intake location: Unit 2 and 3 intake
- Discharge location: Unit 2 and 3 discharge, discharge point common to all units
- Water quality parameters measured: conductivity, pH and DO
- DOC and POC measured: no
- Intake and discharge velocity: unknown

Operating Conditions During Sampling:

- Number of units in operation: varied between 1 and 2
- Number of pumps in operation: varied between 5-11, near full capacity
- Temperature: Intake range: 11.2-24.3 °C
  - Discharge range: 19-36 °C
  - ΔT ranged from 9-12 °C
- Biocide use was not noted

Survival Estimation:

- Number of sampling events: 22
- Total number of samples collected: unknown
- Total number of organisms collected: 4,496
- Number of organisms entrained per year: unknown
- Fragmented organisms: not discussed
- Equal number of organisms collected at intake and discharge: more at discharge
- Most abundant species: striped bass, white perch, bay anchovy and herrings
- Stunned larvae: included in initial survival proportion
- Dead and opaque organisms: not discussed
- Latent survival: observed in aerated glass jars for 96 hours
- Data: was summarized and averaged over the entire sampling period
- Controls: survival in the intake samples was considered to be the control
- Initial intake survival range: 26-48% for striped bass; 15-48% for white perch
  - 18% for herring; 2% for bay anchovy
- Initial discharge survival range: 0-34% for striped bass; 0-37% for white perch
  - 0-8% for herring; 0% for bay anchovy
- Calculation of Entrainment Survival: Discharge survival/ Intake survival
- Standard errors were presented
- Significant differences were tested between the intake and discharge survival
- Significantly lower survival at discharge: striped bass YSL, PYSL and juveniles
  - white perch PYSL
  - herring PYSL
- Survival calculated for species with fewer than 100 organisms collected: yes
- Egg survival: none were alive in either the intake or discharge samples
- Larval survival: decreased markedly within 24 hours of collection.
- Raw data: were not provided to verify results
- Temperature effects: at temps. >30 °C, no striped bass or white perch survived also 0% survived when both Unit 2 and 3 were running
- Mechanical effects: not discussed
- Quality control: sorting efficiency checks, color coded labeling, SOPs
- Peer review: not mentioned, study was conducted for the facility

Indian Point Generating Station

Hudson River, NY

1979 Study

Ecological Analysts, 1981d

Sampling: Dates: March 12-22 and April 30-August 14
Samples collection frequency: March: 4 times per week, rest was 2 consecutive days per week
Times of peak abundance: coincided with spawning of targeted species
Time: 1700 to 0200
Number of replicates: unknown
Intake and discharge sampling: simultaneous sampling
Elapsed collection time: 15 minutes
Method: March sampling: two pump/larval table combination
April-August sampling: rear-draw plankton sampling flume at intake pumpless plankton sampling flume at discharge
Depth: mid-depth for intake, 1-5 m below surface for discharge
Intake location: of Units 2 and 3
Discharge location: in discharge canal for Unit 3 and at end of canal
Water quality parameters measured: conductivity, pH and DO
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: one unit not operating March 20-26 only one continuously April-August
Number of pumps in operation: varied between 5 and 12
Temperature: Discharge range: 12.0-21.9 °C in March; 24-32.9 °C
ΔT data not provided
Biocide use was not noted

Survival Estimation:
Number of sampling events: 8 in March; 32 in April-August
Total number of samples collected: unknown
Total number of organisms collected: 478 in March; 2,362 April-August
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: varied
Most abundant species: Atlantic tomcod, striped bass, white perch, herring, bay anchovy
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars with filtered water for 96 hours
Data: sorted by discharge temperature in March; combined all April-August
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 43-68% for Atlantic tomcod; 39-56% for striped bass
13-33% for white perch; 23% for herrings
10% for bay anchovy
Initial discharge survival range: 14-46% for Atlantic tomcod; 62-77% for striped bass
24-70% for white perch; 28% for herrings
6% for bay anchovies
Calculation of Entrainment Survival: For the fish larvae samples, a difference in stress associated with the different sampling techniques at the intake and discharge was given as the reason why discharge survival was higher than intake survival for each taxa sampled. Thus, entrainment survival was not calculated.
Standard errors were presented
Significant differences were tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: determined by translucency and hatching success;
33% hatched in discharge samples; 44% in intake samples
Larval survival: decreased markedly within 3 hours of collection.
Raw data: were not provided to verify results.
Temperature effects: no white perch or striped bass survival at temps. >33 °C
Mechanical effects: unknown extent
Quality control: sorting efficiency checks, color coded labels and SOPs
Peer review: not mentioned, study was conducted for the facility

Indian Point Generating Station

Hudson River, NY

1980 Study

Ecological Analysts, 1982b

Sampling: Dates: April 30-July 10
- Samples collection frequency: 4 consecutive nights per week
- Times of peak abundance: coincided with primary spawning of target species
- Time: 1600-0200 hours
- Number of replicates: unknown
- Intake and discharge sampling: initiated simultaneously
- Elapsed collection time: 15 minutes
- Method: intake: rear-draw plankton sampling flume mounted on raft discharge: pumpless plankton sampling flume mounted on raft
- Depth: unknown
- Intake location: Unit 3 intake
- Discharge location: discharge port number 1
- Water quality parameters measured: conductivity, DO, pH
- DOC and POC measured: no
- Intake and discharge velocity: intake: 0.3 m/sec; discharge 3 m/sec

Operating Conditions During Sampling:
- Number of units in operation: varied between 1 and 2, Unit 2 offline June 4-11
- Number of pumps in operation: varied between 5 and 11
- Temperature: intake range: 11.3-25.1 °C
  - discharge range: 23-31 °C
  - ΔT data not presented
- Biocide use was not noted

Survival Estimation:
- Number of sampling events: 44
- Total number of samples collected: unknown
- Total number of organisms collected: 2,355
- Number of organisms entrained per year: unknown
- Fragmented organisms: not discussed
- Equal number of organisms collected at intake and discharge: more at discharge
- Most abundant species: striped bass, white perch, bay anchovies
- Stunned larvae: included in initial survival proportion
- Dead and opaque organisms: not discussed
- Latent survival: observed in aerated glass jars for 96 hours
- Data: combined by discharge temperature
- Controls: survival in the intake samples was considered to be the control
- Initial intake survival range: 95% for striped bass
  - 93% for white perch
  - 32% for bay anchovies
  - 40% recirculation can occur so intake mortality may include organisms which were dead due to a previous passage through the facility
- Initial discharge survival range: 50-81% for striped bass
  - 0-90% for white perch
  - 0-4% for bay anchovy
- Calculation of Entrainment Survival: Discharge survival / intake survival
- Confidence intervals / standard deviations: were not presented.
- Significant differences were tested between the intake and discharge survival
- Survival calculated for species with fewer than 100 organisms collected: yes
- Egg survival: hatching success: 82% in intake, 47% in discharge
- Larval survival: decreased markedly within 3 hours of collection.
- Raw data: were not provided to verify results
- Temperature effects: little survival at discharge temps >33 °C
- Mechanical effects: unknown
- Quality control: sorting efficiency checks, color coded labels and SOPs
- Peer review: not mentioned, study was conducted for the facility

Indian Point Generating Station

Hudson River, NY

1985 Study

EA Science and Technology, 1986

Sampling: Dates: May 27-June 29
Samples collection frequency: daily
Times of peak abundance: sampling did not occur during time of peak densities
Time: daytime, switched to nighttime after June 11 due to low sample sizes
Number of replicates: unknown
Intake and discharge sampling: simultaneous sampling
Elapsed collection time: 13-15 minutes (200 m^3)
Method: barrel sampler with 2 coaxial cylinders with 505 μm mesh one sampler at intake; 2 at discharge
Depth: unknown
Intake location: in front of Unit 2 intake
Discharge location: in discharge canal downstream from Unit 2 discharge
Water quality parameters measured: salinity, DO, pH and conductivity
DOC and POC measured: no
Intake and discharge velocity: discharge: 2.8-10 ft/sec

Operating Conditions During Sampling:
Number of units in operation: varied between 1 and 2
Number of pumps in operation: unknown
Temperature: Intake range: 20.3-22.9 °C
Discharge range: 26.6-30.3 °C
ΔT range: 4.6-8.5 °C
Biocide use: residual chlorine not measured

Survival Estimation:
Number of sampling events: 49
Total number of samples collected: unknown
Total number of organisms collected: 457
Cited low efficiency of sampling gear as part of reason for low numbers of organisms sampled
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal no. of organisms collected at intake and discharge: 3X more at discharge
Most abundant species: bay anchovy
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars for 48 hours
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 23% for bay anchovy
Initial discharge survival range: 6% for bay anchovy
Calculation of Entrainment Survival: Discharge survival / Intake survival
Confidence intervals (95%) were presented
No calculations of significance due to small sample size
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: none collected
Larval survival: decreased markedly within 3 hours of collection.
Raw data: were not provided to verify results
Temperature effects: unknown, too narrow of temperature range sampled
Mechanical effects: New dual-speed pumps installed in Unit 2 in 1984, study was conducted to determine whether extent of mechanical mortality differed from previous studies.
Quality control: SOPs, reanalysis of samples, double keypunch of all data
Peer review: not mentioned, study was conducted for the facility

Indian Point Generating Station

Hudson River, NY

1988 Study

EA Engineering, Science, and Technology, 1989

Sampling: Dates: June 8-June 30
- Samples collection frequency: unclear
- Times of peak abundance: sampling not at peak densities for targeted species
- Time: afternoon and evening hours
- Number of replicates: varied, unknown number per day
- Intake and discharge sampling: simultaneous with twice as many at discharge
- Elapsed collection time: 15 minutes
- Method: rear-draw sampling flumes, 1 at intake and 2 at discharge
- Depth: unknown at intake, surface at bottom at discharge
- Intake location: on raft in front of Intake 35
- Discharge location: downstream from flow of Units 2 and 3
- Water quality parameters measured: salinity, DO, pH
- DOC and POC measured: no
- Intake and discharge velocity: discharge 2.2-10.0 ft/sec

Operating Conditions During Sampling:
- Number of units in operation: unknown
- Number of pumps in operation: unknown
- Temperature: Intake range: 20.3-23.8 °C
  - ΔT range: not provided
- Biocide use: residual chlorine not monitored

Survival Estimation:
- Number of sampling events: 13
- Total number of samples collected: unknown
- Total number of organisms collected: 12,333
- Number of organisms entrained per year: unknown
- Fragmented organisms: not discussed
- Equal number of organisms collected at intake and discharge: 10X more in discharge
- Most abundant species: bay anchovy, striped bass, white perch
- Stunned larvae: included in initial survival proportion
- Dead and opaque organisms: not discussed
- Latent survival: observed in aerated glass jars for 24 hours
- Data: was summarized and averaged over the entire sampling period; discharge survival estimates include data from direct release studies and combined surface and bottom samples
- Controls: survival in the intake samples was considered to be the control
- Initial intake survival range: 0-8% for bay anchovy; 86-90% for striped bass
- Initial discharge survival range: 0-2% for bay anchovy; 62-68% for striped bass
- Calculation of Entrainment Survival: discharge survival / intake survival
- Standard errors were presented
- Significant differences were not tested between the intake and discharge survival
- Survival calculated for species with fewer than 100 organisms collected: yes
- Egg survival: none survived in intake and discharge samples
- Larval survival: decreased markedly within hours of collection
- Raw data: were not provided to verify results
- Temperature effects: undetermined effect; too narrow range tested
- Mechanical effects: study was conducted to determine the effect of the installation of dual speed circulating water pumps in Unit 2 in 1984 and variable speed pumps in Unit 3 in 1985; mechanical effects were determined to be main cause of mortality when discharge temperatures are <32 °C
- Quality control: SOPs, sampling stress evaluation, reanalysis of samples, double keypunch data
- Peer review: not mentioned, study was conducted for the facility

Indian River Power Plant

Indian River Estuary

1975-1976 Study

Ecological Analysts, 1978b

Sampling: Dates: July 2, 1975-December 13, 1976
- Samples collection frequency: once or twice monthly
- Times of peak abundance: samples not taken frequently enough to detect
- Time: mostly at night
- Number of replicates: varied
- Intake and discharge sampling: not paired discharge samples not always collected
- Elapsed collection time: approximately 5 minutes or until sufficient # collected
- Method: 0.5 m diameter plankton sled with 505 µm net rinsed in 10L of water of unspecified origin
- Depth: unknown
- Intake location: from foot bridge over intake canal
- Discharge location: in discharge canal under roadway bridge
- Water quality parameters measured: unknown
- DOC and POC measured: no
- Intake and discharge velocity: unknown

Operating Conditions During Sampling:
- Number of units in operation: unknown
- Number of pumps in operation: unknown
- Temperature: Intake range: -0.2-29.2
  - Discharge range: 5.4-39 °C
  - ΔT ranged from 5.2-9.0 °C
- Biocide use was not noted

Survival Estimation:
- Number of sampling events: 27
- Total number of samples collected: 25 intake and 21 discharge
- Total number of organisms collected: unknown
- Number of organisms entrained per year: unknown
- Fragmented organisms: not discussed
- Equal number of organisms collected at intake and discharge: unknown
- Most abundant species: bay anchovy, Atlantic croaker, spot, weakfish, Atlantic menhaden and Atlantic silversides
- Stunned larvae: not discussed
- Dead and opaque organisms: not discussed
- Latent survival: in holding containers in ambient water baths for 96 hours
- Data: sorted based on discharge temperature
- Controls: survival in the intake samples was considered to be the control.
- Initial intake survival range: not provided
- Initial discharge survival range: not provided
- Calculation of Entrainment Survival: not all were counted for most abundant species, a random sample was used instead
- Confidence intervals / standard deviations: were not presented.
- Significant differences were not tested between the intake and discharge survival
- Survival calculated for species with fewer than 100 organisms: unknown
- Egg survival: were alive in either the intake or discharge samples.
- Larval survival: unclear trend
- Raw data: in Appendix B not available to EPA
- Temperature effects: all species had lower survival at discharge temps >20 °C. Only Spot survived above 35 °C though linear regression
- Mechanical effects: unknown, however dye studies performed at this facility and recirculation of discharge water has been shown to occur. The extent to which organisms are entrained repeatedly and the effect this has on the number of organisms that were shown to have died through natural causes or from sampling is not known. Thus some intake mortality may be due to the organism’s previous passage through the facility.
- Quality control: unknown
- Peer review: not mentioned, study was conducted for the facility

Muskingum River Plant

Muskingum River, OH

Literature Review

Ecological Analysts, 1979a

Sampling: No on site sampling conducted

Operating Conditions During Sampling:
No sampling conducted

Survival Estimation:
Analyzed pressure regimes in circulating water system
Measured discharge temperature and ΔT at the facility
Determined that pressure regimes were similar to facilities with entrainment survival studies
Determined that low survival occurs at ΔT >7.8 °C which occurs for a small portion of entrainment season
Reviewed documentation of survival at other steam electric stations
Concluded that potential of survival at this facility was intermediate to high
Peer review: literature review prepared for facility

Northport Generating Station

Long Island Sound, NY

1980 Study

Ecological Analysts, 1981c

Sampling: Dates: April 10-22 and July 10-23
Samples collection frequency: 5 nights per week
Times of peak abundance: attempted to coincide with peak abundance
Time: 1700-0100 hours
Number of replicates: unknown
Intake and discharge sampling: simultaneous
Elapsed collection time: 15 minutes
Method: floating rear-draw sampling flume with 505 µm mesh screens with ambient water injection system
Depth: intake: 2-8 m below surface; discharge: 1.5 m
Intake location: immediately in front of Unit 2 or 3 trash racks
Discharge location: immediately in front of Unit 2 or 3 seal well
Water quality parameters measured: DO, pH, conductivity
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: Discharge range: 15.9-35 °C, average 19.9 in April and 33.6 in July
ΔT ranged from 8.6-15.0 °C
Biocide use was not noted

Survival Estimation:
Number of sampling events: 20
Total number of samples collected: 162
Total number of organisms collected: 884 in April and 76 in July
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: more at discharge
Most abundant species: American sand lance, winter flounder, northern pipefish
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated jars of filtered ambient water for 48 hours
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 66% for American sand lance; 85% for winter flounder
28% for bay anchovy
Initial discharge survival range: 17% for American sand lance; 35% for winter flounder
0% for bay anchovy
Calculation of Entrainment Survival: discharge survival / intake survival
Stated that survival estimate based on 4 assumptions: that the survival at the discharge is the product of the probabilities of surviving entrainment and sampling, that the survival at the intake is the probability of surviving sampling, that at the discharge there is no interaction between the two stresses, and each life stage consists of a homogenous population in which all individuals have the same probability of surviving to the next life stage
Standard errors were presented
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: none collected
Larval survival: decreased markedly within 6 hours of collection.
American sand lance significantly larger in intake sample
Raw data: were provided to verify results
Temperature effects: not studied
Mechanical effects: not studied
Quality control: SOPs, color coded labels, sorting efficiency checks
Peer review: not mentioned, study was conducted for the facility

Oyster Creek Nuclear Generating Station

Barnegat Bay, NJ

1985 Study

EA Engineering, Science, and Technology, 1986

Sampling: Dates: February-August
Samples collection frequency: unknown
Times of peak abundance: smaller samples collected during peak densities
Time: unknown
Number of replicates: unknown
Intake and discharge sampling: discharge collected 2 minutes after intake
Elapsed collection time: approximately 10 minutes
Method: barrel sampler with 2 nested cylindrical tanks with 331 mm mesh
Depth: unknown
Intake location: northernmost intake groin west of recirculation tunnel
Discharge location: easternmost condenser discharge point
Water quality parameters measured: DO, salinity and pH in latent studies
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: Discharge range: 13.5-39.3 °C
ΔT ranged from -0.2-12.1 °C
Biocide use: chlorine concentration was measured, but not detected

Survival Estimation:
Number of sampling events: 20
Total number of samples collected: 13 for bay anchovy eggs, 10 for bay anchovy larvae and 5 for winter flounder
Total number of organisms collected: 60,274
Number of organisms entrained per year: 619 million to 15.4 billion
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: no
Most abundant species: bay anchovy and winter flounder
Stunned larvae: included in initial survival proportion; as well as damaged
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars in water baths for 96 hours
Data: grouped by 3 day long sampling events
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 38-91% for bay anchovy larvae
77-96% for winter flounder larvae
Initial discharge survival range: 0-71% for bay anchovy larvae
32-92% for winter flounder larvae
Calculation of Entrainment Survival: Discharge survival / Intake survival
Confidence intervals / standard deviations: were not presented
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: no
Egg survival: based on translucency and hatching success
Larval survival: decreased markedly within 3 hours of collection
Raw data: were not provided to verify results
Temperature effects: no bay anchovy larvae survived at discharge >35 °C
Mechanical effects: 18.8% of mortality at discharge temperatures 25.9-27.0 °C
Quality control: unknown
Peer review: not mentioned, study was conducted for the facility

Pittsburg Power Plant

Suisun Bay, CA

1976 Study

Stevens and Finlayson, 1978

Sampling: Dates: April 28-July 10

Samples collection frequency: once per week
Times of peak abundance: unknown
Time: varied, about 25% of all samples collected at night
Number of replicates: typically 3
Intake and discharge sampling: paired at closest time and temperature
Elapsed collection time: 1-2 minutes
Method: 505 micron mech conical nylon plankton net with 0.58 m plastic collecting tubes on cod end; towed net on boat at 0.6 ft/sec
Depth: mid-depth
Intake location: in river near intake
Discharge location: in river near discharge
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:

Number of units in operation: unknown
Number of pumps in operation: unknown
Temperature: Intake temperature: 18-30 °C
  Discharge temperature 27-37 °C
Biocide use was not noted

Survival Estimation:

Number of sampling events: 7
Total number of samples collected: unknown
Total number of organisms collected: 462 (585 at north shore control)
Number of organisms entrained per year: unknown
Fragmented organisms: enumerated in one replicate tow higher proportion of unidentifiable fragments in intake
  43% in intake; 19% in discharge
Equal number of organisms collected at intake and discharge: more at intake
Most abundant species: striped bass
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: not studied
Data: was summarized by mean larval length
Controls: survival in the intake samples was considered to be the control additional controls in center of river and north shore control site at north shore away from intake had lower mortality rates
Initial intake survival range: 49-93% for striped bass
Initial discharge survival range: 8-87% for striped bass
Calculation of Entrainment Survival: paired discharge survival divided by paired intake survival
Confidence intervals / standard deviations: were not presented
Significant differences were not tested between the intake and discharge survival
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not studied
Larval survival: increased survival with greater larval length
Raw data: were not provided to verify results
Temperature effects: mortality increased with increase in discharge temperature higher mortality with discharge temp. >31 and $\Delta T > 7$ °C
  linear regression showed that half died at temps >33.3 °C
  0% survival at temperatures of 38 °C
Mechanical effects: stated not as much of an effects as temperature; recirculated water may be cause of some intake mortality
Quality control: not discussed
Peer review: study conducted by California Fish and Game with funds provided by facility

Port Jefferson Generating Station

Long Island Sound, NY

1978 Study

Ecological Analysts, 1978d

Sampling: Dates: April 21-26
Samples collection frequency: 4 times in one week
Times of peak abundance: unclear if sampling coincided with peak densities
Time: 1800-0200 hours
Number of replicates: varied between 7-10 per sampling date.
Intake and discharge sampling: simultaneous collection, equal number at sites
Elapsed collection time: 15 minutes
Method: pump (2 different types) and larval table
Depth: intake: 2 m below mean low water mark
discharge: 1 m below mean low water mark
Intake location: in front of trash racks of intake of Unit 4
Discharge location: in common seal well structure for Units 3 and 4
Water quality parameters measured: none
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: unknown
Number of pumps in operation: 4
Temperature: Intake range: 7-9 °C
Discharge range: 10-18 °C
ΔT ranged from 2-11 °C
Biocide use: sampling coincided with time of no biocide use

Survival Estimation:
Number of sampling events: 5
Total number of samples collected: 94
Total number of organisms collected: 1,104
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: no, quite different
Most abundant species: winter flounder, sand lance, sculpin, American eel, fourbeard rockling eggs
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not discussed
Latent survival: observed in aerated glass jars in water bath for 96 hours
Data: was summarized and averaged over the entire sampling period
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 42-60% for winter flounder PYSL;
11-67% for sand lance PYSL
33-84% sculpin PYSL
25-100% American eel juveniles
11-26% fourbeard rockling eggs
Initial discharge survival range: 0-43% for winter flounder PYSL
12-40% for sand lance PYSL
88% for sculpin PYSL
94-96% for American eel juveniles
19-21% fourbeard rockling eggs
Calculation of Entrainment Survival: Discharge survival / intake survival
Confidence intervals / standard deviations: were not presented.
Significant differences were tested between the intake and discharge survival
Significantly lower survival in discharge: winter flounder PYSL
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: classified by observation only, based on transparency
Larval survival: no information given on length or other life stages
Raw data: were provided to verify results
Temperature effects: no apparent relationship temperature and survival;
low numbers collected at a narrow range of discharge temperatures
Mechanical effects: assumed cause of all mortality
Quality control: color coded labeling, checks of sorted samples, and SOPs
Peer review: not mentioned, study was conducted for the facility

PG&E Potrero Power Plant

San Francisco Bay, CA

1979 Study

Ecological Analysts, 1980b

Sampling: Dates: January
- Samples collection frequency: unknown
- Times of peak abundance: unclear if sampling corresponded with peak densities
- Time: unknown
- Number of replicates: unknown
- Intake and discharge sampling: equal number but timing unknown
- Elapsed collection time: 15 minutes
- Method: 2 pumps and larval table with filtered ambient temperature water flow
- Depth: mid-depth
- Intake location: directly in front of intake skimmer wall
- Discharge location: at point where discharge enters San Francisco Bay
- Water quality parameters measured: none
- DOC and POC measured: no
- Intake and discharge velocity: unknown

Operating Conditions During Sampling:
- Number of units in operation: unknown
- Number of pumps in operation: unknown
- Temperature: Discharge range: 18-19.5 °C
  - ΔT range not presented
- Biocide use: not used during sampling events

Survival Estimation:
- Number of sampling events: 11
- Total number of samples collected: 25
- Total number of organisms collected: 1,262
- Number of organisms entrained per year: estimated for Units 1-3: 3 billion
- Fragmented organisms: not discussed
- Equal number of organisms collected at intake and discharge: approx. same
- Most abundant species: Pacific herring
- Stunned larvae: issue of stunned larvae not discussed in study
- Dead and opaque organisms: not discussed
- Latent survival: observed in aerated glass jars in water baths for 96 hours
- Data: was summarized and averaged over the entire sampling period
- Controls: survival in the intake samples was considered to be the control
- Initial intake survival range: 22% for Pacific herring
- Initial discharge survival range: 16% for Pacific herring
- Calculation of Entrainment Survival: Discharge survival/ Intake survival
- Confidence intervals / standard deviations: were not presented.
- Significant differences were not tested between the intake and discharge survival
- Survival calculated for species with fewer than 100 organisms collected: no
- Egg survival: not studied
- Larval survival: Based on results of this study, an estimate of 75% entrainment survival was used for all species and life stages entrained at this facility under all conditions
- Raw data: were not provided to verify results
- Temperature effects: discharge temps <30 °C over 99.5% of time
- Mechanical effects: most likely cause of mortality due to low temperatures
- Quality control: unknown
- Peer review: not mentioned, study was conducted for the facility

Quad Cities Nuclear Station

Mississippi River, IL

1978 Study

Hazleton Environmental Science, 1978

Sampling: Dates: June 19-28
Samples collection frequency: varied
Times of peak abundance: unknown
Time: afternoon, evening or nighttime hours
Number of replicates: varied
Intake and discharge sampling: unknown if paired
Elapsed collection time: did not exceed 60 seconds
Method: from boat, with 0.75 m conical plankton net with 526 μm mesh and an unscreened 5 L bucket attached
Depth: mid-depth at intake, near surface at discharge
Intake location: intake forebay
Discharge location: in discharge canal common to all units; held at discharge temp for 8.5 minutes to simulate passage through canal then cooled to ambient temp. plus 3.5 °C before sorting
Water quality parameters measured: DO
DOC and POC measured: no
Intake and discharge velocity: exceed 1 ft/sec

Operating Conditions During Sampling: completely open cycle mode
Number of units in operation: power output 41-99%, Unit 1 offline on June 22
Number of pumps in operation: all 3 regardless of power load
Temperature: Intake range: 21.5-26.5 °C
Discharge range: 28.0-39.0 °C
ΔT ranged from 5.5-14.8 °C
Biocide use: not used during sampling

Survival Estimation:
Number of sampling events: 5
Total number of samples collected: unknown
Total number of organisms collected: 2,587
Number of organisms entrained per year: unknown
Fragmented organisms: not discussed
Equal number of organisms collected at intake and discharge: more at discharge
Most abundant species: freshwater drum and minnows
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: assumed dead from natural mortality prior to collection and omitted from further analysis; 27% of all sampled
Latent survival: observed in aerated glass jars for 24 hours on June 22-23, 26-27
Data: combined by % power of station operation
Controls: survival in the intake samples was considered to be the control
Initial intake survival range: 0-80% for all species
0-100% for freshwater drum
48-100% for minnows
Initial discharge survival range: 0-84% for all species
0-71% for freshwater drum
2-75% for minnows
Calculation of Entrainment Survival: Discharge survival/Intake survival (minus dead and opaque individuals)
When discharge survival was greater than intake survival, the study indicated that entrainment survival could not be calculated, rather than assume 100% entrainment survival
Confidence intervals/standard deviations: were not presented.
Significant differences were tested between the intake and discharge survival
Significantly lower survival in discharge: throughout study
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: not presented
Larval survival: decreased with increasing power output and discharge temperature
3% survival for all species when the facility operated near full capacity (96-99%) and discharge temperatures exceeded 37.9 °C
Raw data: were provided to verify results, however replicate sample data not presented
Temperature effects: lower survival with higher discharge temperatures >30 °C
Mechanical effects: suggest mechanical effects cause 20-25% of mortality
Quality control: not discussed
Peer review: not mentioned, study was conducted for the facility

Quad Cities Nuclear Station

Mississippi River, IL

1984 Study

Lawler, Matusky & Skelly Engineers, 1985

Sampling: Dates: April 25-June 27

- July sampling canceled as 100% mortality was suspected
- Samples collection frequency: weekly
- Times of peak abundance: unknown
- Time: unknown
- Number of replicates: unknown
- Intake and discharge sampling: unknown if paired
- Elapsed collection time: unknown
- Method: from boat, with 0.75 m conical plankton net with 526 µm mesh and an unscreened 5 L bucket attached
- Depth: 1.5 m for intake, surface for discharge
- Intake location: intake forebay
- Discharge location: in discharge canal; held at collection temperature for 8.5 min. then cooled to 3.5 °C above ambient temperature with an ice bath, in all held for over 20 minutes before sorting
- Water quality parameters measured: none
- DOC and POC measured: no
- Intake and discharge velocity: samples collected at <0.8 ft/sec

Operating Conditions During Sampling: operating at 40.2 to 50.7% capacity

- Number of units in operation: Unit 1 offline for refueling; both units offline on May 9
- Number of pumps in operation: all 3 on all dates except on May 9
- Temperature: Intake range: 11-24.4 °C
    - Discharge range: 12-37 °C
    - ΔT ranged from 9.5 to 14.5 °C; 1 °C on May 9 when offline
- Biocide use: not used during sampling

Survival Estimation:

- Number of sampling events: 8
- Total number of samples collected: unknown
- Total number of organisms collected: 3,967
- Number of organisms entrained per year: unknown
- Fragmented organisms: not discussed
- Equal number of organisms collected at intake and discharge: approx. same total
- Most abundant species: freshwater drum, carp and buffalo
- Stunned larvae: not discussed
- Dead and opaque organisms: omitted from analysis; assumed dead before collection, 2,979 opaque individuals were collected
    - (75% of total, 87% of all discharge sample. range: 0 to 99% in samples)
    - None were found to be dead and opaque in discharge on May 9 when offline and ΔT was 1° C.
- Latent survival: not discussed
- Data: combined by species and sampling date
- Controls: survival in the intake samples was considered to be the control
- Initial intake survival range: results not presented, only number alive
    - 10-81% were dead and opaque
- Initial discharge survival range: results not presented, only number alive
    - 24-99% were dead and opaque
- Calculation of Entrainment Survival: Discharge survival / Intake survival
- Confidence intervals / standard deviations: were not presented.
- Significant differences were not tested due to low numbers collected
- Survival calculated for species with fewer than 100 organisms collected: yes
- Egg survival: not studied
- Larval survival: too little information to make any assumption of survival
- Raw data: were not provided to verify results; totals collected per species not presented; actual numbers of dead and opaque not provided
- Temperature effects: no sampling in July when discharge temps >37 °C
- Mechanical effects: not discussed
- Quality control: 100% reanalysis quality control
- Peer review: not mentioned, study was conducted for the facility

Roseton Generating Station

Hudson River, NY

1975 Study

Ecological Analysts, 1976c

Sampling: Dates: May 29th-November 18th
Collection frequency: varied from 4 times per week to once every 2 weeks.
Times of peak abundance: greater frequency of collection
Time: varied but generally occurred between dusk and dawn
Number of replicates: varied between 3 and 14 for each date
Intake and discharge sampling: paired but timing not standardized
Elapsed collection time: not noted
Method: pump/larval table
Depth: mid-depth at both the intake and discharge
Intake location: in front of the trash rack
Discharge location: from the seal well before the end of the discharge pipe
Water quality parameters measured: none mentioned
DOC and POC measured: no
Intake and discharge velocity: not given

Operating Conditions During Sampling:
Number of units in operation: varied between 1 and 2
Number of pumps in operation: varied between 2 and 3
Temperature: ΔT ranged from 3 to 13 °C, intake and discharge T not given
Biocide use: not noted

Survival Estimation:
Number of sampling events: 41
Number of samples: 672
Number of organisms collected: 3,667
Number of organisms entrained per year: not discussed
Fragmented organisms collected: not discussed
Equal number collected from intake and discharge: differed by as much as 3.2X
Most abundant species: striped bass, white perch, alewife and blueback herring
Stunned larvae: included in initial survival proportion
Dead and opaque organisms: not mentioned
Latent survival: observed in aerated glass jars for 96 hours.
Data: summarized and averaged over the entire sampling period
Controls: survival in intake sample; no other control
Initial intake survival range: 57 to 80% for striped bass
  0 to 71% for white perch
  58 to 65% for herrings
Initial discharge survival range: 62% for striped bass
  29% for white perch
  26% for herrings
Calculation of entrainment survival: Discharge Survival/Intake Survival
Study noted that survival cannot be calculated with insufficient data or when intake survival is very low
Confidence intervals/ standard deviations: not presented
Significant differences: tested between the intake and discharge survival
Significantly lower survival in discharge: striped bass YSL and PYSL
  white perch PYSL
  herring PYSL and juveniles
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: none alive in either the intake or discharge samples
Larval survival: decreased markedly within 3 hours of collection
Size effects: survival by larval length was not studied
Raw data: were not provided to verify results
Temperature effects: not provided
Mechanical effects: not provided
Quality control: double check after initial sorting; monitoring of data entry
Peer review: not mentioned; study was conducted for the facility

Roseton Generating Station

Hudson River, NY

1976 Study

Ecological Analysts, 1978e

Sampling: Dates: June 14th-July 30th
Samples collection frequency: 4 nights per week
Times of peak abundance: coincided with *Morone* spp. spawning season
Time: 1700 to 0300 EST
Number of replicates: actual numbers not give, an average of 12 per night stated
Intake and discharge sampling: pairing unknown
Elapsed collection time: 15 minutes
Method: pump/ larval table combination
Depth: mid-depth for both intake and discharge
Intake location: 1 m in front of trash rack
Discharge location: in seal well near end of discharge pipe
Water quality parameters measured: no
DOC and POC measured: no
Intake and discharge velocity: unknown

Operating Conditions During Sampling:
Number of units in operation: varied between 0 and 2
Number of pumps in operation: not given
Temperature: Intake temperature range: 18.7-27.5 °C
Discharge temperature ranged 24-37 °C
ΔT ranged from 1-10 °C
Biocide use: not noted

Survival Estimation:
Number of sampling events: 27
Total number of samples collected: unknown
Total number of organisms collected: 3,491
Number of organisms entrained per year: not given
Fragmented organisms: not discussed
Equal number of organisms collected at intake / discharge: no, up to 5.7X more
Most abundant species: herrings, white perch and striped bass
Stunned larvae: were included in initial survival proportion
Dead and opaque organisms: not mentioned
Latent survival: observed in aerated glass jars for 96 hours
Data: combined by discharge temperature range: 34-30.5 and 30.6 to 37 °C
Controls: Survival in the intake samples; no other control.
Initial intake survival range: 74-100% for striped bass
53-94% for white perch
49-68% for herrings
Initial discharge survival range: 14-80% for striped bass
6-56% for white perch
5-29% for herrings
Calculation of Entrainment Survival: Discharge Survival/ Intake Survival
Data for many taxa or life stages collected were insufficient for analysis
Confidence intervals / standard deviations: were not presented
Significant differences were tested between the intake and discharge survival
Significantly lower survival in discharge: striped bass PYSL
white perch PYSL and juveniles
herring PYSL and juveniles
Survival calculated for species with fewer than 100 organisms collected: yes
Egg survival: data not presented
Larval survival: decreased markedly within 3 hours of collection.
Size effects: survival by larval length was not studied
Raw data: were not provided to verify results
Temperature effects: significant decrease in survival at discharge temp >30 °C
Mechanical effects: unknown
Quality control: double check after initial sorting; monitoring of data entry
Peer review: not mentioned, study was conducted for the facility

Roseton Generating Station

Hudson River, NY

1977 Study

Ecological Analysts, 1978f

Sampling: Dates: March 3-17 and May 31st-July 15th.
- Samples collection frequency: unknown; usually 4 nights per week was stated
- Times of peak abundance: coincided with spawning of targeted species
- Time: 1700 to 0300 hours EST
- Number of replicates: unknown; an average of 8 to 10 per night was stated
- Intake and discharge sampling: unknown if samples were collected in pairs
- Elapsed collection time: 15 minutes
- Method: pump/larval table combination
  - ambient water flow in table to reduce thermal exposure during sorting
- Depth: mid-depth
- Intake location: in front of trash racks
- Discharge location: from seal well 244 m from end of discharge pipe
- Water quality parameters measured: no
- DOC and POC measured: no
- Intake and discharge velocity: unknown

Operating Conditions During Sampling:
- Number of units in operation: unknown
- Number of pumps in operation: varied between 2 and 4
- Temperature: Intake temperature: 0.5-5.5 °C (March); 11-27 °C (June/July)
  - Discharge temperature: 7-17 °C (March); 24-36 °C (June/July)
  - ΔT range: unknown
- Biocide use was not noted

Survival Estimation:
- Number of sampling events: unknown
- Total number of samples collected: unknown
- Total number of organisms collected: 6,973
- Number of organisms entrained per year: unknown
- Fragmented organisms: if >50% present, organism was counted
- Equal number collected at intake and discharge: up to 2.3X more in discharge
- Most abundant species: atlantic tomcod, herrings, striped bass, white perch
- Stunned larvae: included in initial survival proportion
- Dead and opaque organisms: not mentioned
- Latent survival: observed in aerated glass jars for 96 hours
- Data: combined by discharge temperature range, <29.9, 30.0-32.9, >33 °C
- Controls: Survival in the intake samples was considered to be the control
- Initial intake survival range: 39% for Atlantic tomcod
  - 0 to 50% for striped bass
  - 0 to 33% for white perch
  - 0 to 59% for herrings
- Initial discharge survival range: 16% for Atlantic tomcod
  - 0 to 83% for striped bass
  - 0 to 50% for white perch
  - 0 to 14% for herrings
- Calculation of Entrainment Survival: Discharge Survival / Intake Survival
- Confidence intervals / standard deviations: were not presented.
- Significant differences were tested between the intake and discharge survival
- Significantly lower survival in discharge: Atlantic tomcod YSL
  - striped bass PYSL
  - white perch PYSL
  - herring PYSL and juveniles
- Survival calculated for species with fewer than 100 organisms collected: yes
  - number of some taxa and life stage were too low to estimate survival reliably
- Egg survival: data not presented
- Larval survival: decreased markedly within 3 hours of collection.
  - increased with larval length
- Raw data: were not provided to verify results
- Temperature effects: survival decreased at temperatures above 30 °C
  - very low survival at temperatures >33 °C (0 to 3%)
- Mechanical effects: survival may increase with number of pumps operating
- Quality control: color coded labels, immediate checks of sorted sample, SOP's
- Peer review: not mentioned, study was conducted for the facility

Roseton Generating Station

Hudson River, NY

1978 Study

Ecological Analysts, 1980c

Sampling: Dates: March 13-23 and June 6-July 13
 Samples collection frequency: 3-4 nights per week
 Times of peak abundance: coincided with spawning of targeted species
 Time: 1700 to 0300 EDT
 Number of replicates: 4 to 10 per night
 Intake and discharge sampling: unknown if paired samples
 Elapsed collection time: 15 minutes
 Method: pump/ larval table combination with fine mesh
  ambient water flow to table to minimize thermal exposure when sorting
 Depth: mid-depth
 Intake location: in front of trash rack
 Discharge location: in seal well 244 m from end of discharge pipe
 Water quality parameters measured: none
 DOC and POC measured: no
 Intake and discharge velocity: unknown

Operating Conditions During Sampling:
 Number of units in operation: varied between 1 and 2
 Number of pumps in operation: varied between 2 and 3
 Temperature: Intake temperature: 0.2-5.5 °C (March), 19.8-24.0 °C (June/July)
  Discharge temperature: 10-19 °C (March), 24-37 °C (June/July)
  ΔT range was not given
 Biocide use was not noted

Survival Estimation:
 Number of sampling events: 30
 Total number of samples collected: 256
 Total number of organisms collected: 5,308
 Number of organisms entrained per year: unknown
 Fragmented organisms: counted if >50% of organism was present
  22% of Atlantic tomcod could not be identified to life stage due to damage
 Equal number of organisms collected at intake and discharge: varied
 Most abundant species: herrings, white perch, striped bass, Atlantic tomcod
 Stunned larvae: included in initial survival proportion
 Dead and opaque organisms: not mentioned
 Latent survival: observed in aerated glass jars for 96 hours
 Data: combined by discharge temperature range <29.9, 30.0-32.9, >33 °C
  also combined by larval length
 Controls: Survival in the intake samples was considered to be the control
 Initial intake survival range: 75-84% for Atlantic tomcod
  8-100% for striped bass
  0-93% for white perch
  0-67% for herrings
 Initial discharge survival range: 23-33% for Atlantic tomcod
  0-50% for striped bass
  0-100% for white perch
  0-18% for herrings
 Calculation of Entrainment Survival: Discharge survival/ Intake survival
 Confidence intervals/standard deviations: were not presented
 Significant differences were tested between the intake and discharge survival
 Significantly lower survival in discharge: Atlantic tomcod YSL and PYSL
  striped bass PYSL
  white perch PYSL
  herring PYSL
 Survival calculated for species with fewer than 100 organisms collected: yes
  samples sizes of some taxa and life stages were too small to analyze survival
 Egg survival: data not presented
 Larval survival: decreased markedly within 3-6 hours of collection
  increased with larval length
 Raw data: consolidated data by temp. and length was provided; not by sample
 Temperature effects: significant decrease in survival at temperatures >24 °C
  very little survival at temperatures >30 °C
 Mechanical effects: lower tomcod survival in discharge w/o thermal effects
 Quality control: color coded labels, checks of sorted samples, SOP's
 Peer review: not mentioned, study was conducted for the facility

Roseton Generating Station

Hudson River, NY

1980 Study

Ecological Analysts, 1983

Sampling: Dates: May 26-July 31
  Samples collection frequency: usually 4 nights per week
  Times of peak abundance: coincided spawning of striped bass and white perch
  Time: 1600 to 0200 EDT
  Number of replicates: varied between 1 and 10 per sampling date
  Intake and discharge sampling: unknown if samples were paired
  Elapsed collection time: 15 minutes
  Method: pump/larval table or plankton sampling flume
    ambient water injection system to minimize thermal exposure
  Depth: unknown
  Intake location: from the No. 1B circulating water pump forebay
  Discharge location: from discharge seal well or submerged diffuser port
  Water quality parameters measured: none
  DOC and POC measured: no
  Intake and discharge velocity: unknown

Operating Conditions During Sampling:
  Number of units in operation: varied between 1 and 2
  Number of pumps in operation: varied between 3 and 4
  Temperature: Intake temperature: 17.0-29.0 °C
    Discharge temperature: 21.5-34.5 °C
    ΔT range not given
  Biocide use was not noted

Survival Estimation:
  Number of sampling events: 42
  Total number of samples collected: 1431
  Total number of organisms collected: 4,965
  Number of organisms entrained per year: not given
  Fragmented organisms: counted if >50% of organism was present
    7% of all organisms would not be identified to a life stage due to damage
  Equal no. of organisms collected at intake/ discharge: more samples at discharge
  Most abundant species: herrings, striped bass, white perch
  Stunned larvae: were included in initial survival proportion
  Dead and opaque organisms: not mentioned
  Latent survival: observed in aerated glass jars for 48 hours.
  Data: combined by larval length
  Controls: survival in the intake samples was considered to be the control
  Initial intake survival range: 33-100% for striped bass
    0-75% for white perch
    30-53% for herrings
  Initial discharge survival range: 23-100% for striped bass
    0-88% for white perch
    0-31% for herrings
  Calculation of Entrainment Survival: Discharge survival/Intake survival
  Confidence intervals / standard deviations: were not presented.
  Significant differences were tested for latent survival only
  Survival calculated for species with fewer than 100 organisms collected: yes
  Egg survival: not studied
  Larval survival: decreased markedly within 3-6 hours of collection
    survival increased with larval length
    survival lowest for YSL and highest for juveniles
    survival using flume was very low
  Raw data: only consolidated data were presented, not by sample
  Temperature effects: data not given
  Mechanical effects: number of pumps may not affect survival
  Quality control: color coded labels, SOPs
  Peer review: not mentioned, study was conducted for the facility

Salem Generating Station

Delaware Bay, NJ

1984 Demonstration Study

PSE&G, 1984

Sampling: Dates: 1977-1982
- Samples collection frequency: varied, 1 to 4 times per month
- Times of peak abundance: highest frequency in June and July
- Time: unknown
- Number of replicates: varied from 0 to 13 per sampling event
- Intake and discharge sampling: usually paired with lag time
- Elapsed collection time: 10 minutes
- Method: larval table(1977-1980) or low-velocity flume (1981-1982)
- Depth: mid-depth for intake
- Intake location: at intake bay 11A or 12B, inboard of traveling screen
- Discharge location: discharge standpipe 12 or 22
- Water quality parameters measured: unknown
- DOC and POC measured: no
- Intake and discharge velocity: unknown

Operating Conditions During Sampling:
- Number of units in operation: unknown
- Number of pumps in operation: unknown
- Temperature: Intake temperature: unknown
  - Discharge temperature: unknown
  - ΔT range: unknown
  - Lab simulation studies used to test thermal mortality
- Biocide use: three 30 minute periods of chlorination each day
  - estimated biocide use reduces survival by 6.25%

Survival Estimation:
- Number of sampling events: 0 to 12 per year, 38 in all years combined
- Total number of samples collected: varied per year, 640 in all years combined
- Total number of organisms collected: 5,173 larvae and juvenile fish of 6 taxa
- Number of organisms entrained per year: unknown
- Fragmented organisms: not discussed
- Equal no. of organisms collected at intake/ discharge: unknown
- Most abundant species: spot and alewife
- Stunned larvae: included in initial survival proportion
- Dead and opaque organisms: not mentioned
- Latent survival: tests varied with year, 12 to 96 hours in jars or aquaria
- Data: combined data from all years, collected under all conditions
- Controls: some fish were introduced into the larval table or low velocity flume directly; unclear if organisms passed through facility
- Initial intake survival range: 90.9% for spot
  - 12.5% for herrings
- Initial discharge survival range: 74.1% for spot
  - 7.1% for herrings
- Calculation of Entrainment Survival: Discharge survival/Intake survival
- Estimated survival rates from onsite and simulation studies and compared with results in the literature from other waterbodies to select “the most realistic estimates“
- Confidence intervals / standard deviations: not presented
- Significant differences: not tested
- Survival calculated for species with fewer than 100 organisms collected: unknown
- Egg survival: none collected
- Larval survival: not separated from juvenile survival
- Raw data: was not provided to verify results
- Temperature effects: unknown
- Mechanical effects: tested gear efficiency and related mortality only
- Quality control: not mentioned
- Peer review: not mentioned, study conducted for the facility

Chapter A8: Discounting Benefits

Chapter Contents

A8-1 Timing of Benefits A8-1
A8-2 Discounting and Annualization................. A8-2

Introduction

Discounting refers to the economic conversion of future benefits and costs to their present values, accounting for the fact that individuals tend to value future outcomes less than comparable near-term outcomes. Annualization refers to the conversion of a series of annual costs or benefits of differing amounts to an equivalent annual series of constant costs or benefits. Discounting and annualization are important because these techniques allow the comparison of benefits and costs that occur in different time periods.

For the benefits analysis of the regulatory analysis options for the final section 316(b) regulation for Phase III facilities, EPA's discounting and annualization methodology included three steps. First, EPA developed a time profile of benefits to show when benefits occur. Second, the Agency calculated the total discounted value of the benefits as of the year 2007. Finally, EPA annualized the benefits of the regulatory analysis options over a thirty-year time span. The following sections explain these steps in detail.

A8-1 Timing of Benefits

In order to calculate the annualized value of the welfare gain from the regulatory analysis options considered for the final section 316(b) regulation for Phase III facilities, EPA developed a time profile of total benefits from all Phase III facilities that reflects when benefits from each facility will be realized. EPA first calculated the undiscounted commercial and recreational welfare gain from the expected annual regional reductions in impingement and entrainment (I&E) under each analysis option, based on the assumptions that all facilities in each region have achieved compliance with each respective option and that benefits are realized immediately following compliance. Then, since there are regulatory and biological time lags between the potential promulgation of each respective analysis option and the realization of benefits, EPA created a time profile of benefits that takes into account the fact that benefits do not begin immediately. Since this time profile requires information about facility-specific differences in magnitude and timing of benefits, but benefits were estimated only on a regional basis, EPA approximated benefits from each facility by multiplying total undiscounted regional benefits by the percentage of total regional flow that is attributable to each facility.

Regulatory-related time lags occur because, although the regulatory analysis options take effect at the beginning of 2007, facilities would not need to come into compliance with each respective option until their current NPDES permits expire.[1] EPA used facility-specific permitting information to estimate the lag between the potential promulgation of the regulatory analysis options and the compliance year for each sample facility. The terms of each facility's permit differ, but permits for all Phase III facilities are expected to expire between 2010 and 2014. Thus, EPA estimates that it would take from three to seven years after promulgation of each respective analysis option for Phase III facilities to install technologies to reduce I&E.

The biological time lags that affect the timing of benefits occur because most fish that would be spared from I&E would be in larval or juvenile stages. Since these fish may require several years to grow and mature before commercial and recreational anglers can harvest them, there would be a lag between installation of technologies

---

[1] The final regulation for Phase III facilities is scheduled to be promulgated in June of 2006. However, to simplify the discounting and annualization calculations for the benefit cost analysis of the regulatory analysis options, EPA assumed that the regulation will take effect on January 1, 2007.

to reduce I&E and realization of commercial and recreational angling benefits. For example, a larval fish spared from entrainment (in effect, at age zero) may be caught by a recreational angler at age three, meaning that a three-year time lag arises between the installation of technologies to reduce I&E and the realization of the estimated recreational benefit. Likewise, if a one-year-old fish is spared from impingement and is then harvested by a commercial fisherman at age two, there is a one year lag between the installation of technologies to reduce I&E and the subsequent commercial fishery benefit. In general, fish that tend to be harvested at young ages will have relatively short time lags between implementation of technologies to reduce I&E and the subsequent timing of changes in catch. In contrast, long-lived fish that tend to be caught at relatively older ages would tend to have longer time lags (and, hence, the effects of discounting would be larger, resulting in lower present values).

In order to model the biological lags between installation of technologies to reduce I&E and realization of commercial and recreational benefits, EPA collected species-specific information on ages of fish at harvest to estimate the average time required for a fish spared from I&E to reach a harvestable age. The estimated time lags range from 0.5 years to six years, depending on the life history of each fish species affected. EPA used this information, along with information about the estimated age and species composition of I&E losses in each study region, to develop a benefits recognition schedule for facilities in each region.

Following achievement of compliance, benefits from facilities in most regions are assumed to increase over a seven year period to a long-term, steady state average, equal to the approximated per-facility benefit value discussed above, according to a numerical profile of <0.0, 0.1, 0.2, 0.8, 0.9, 0.95, 1.0>. This profile indicates the fraction of the steady state benefit value (i.e., the percentage of commercial and recreational fish spared from I&E that reach a harvestable age) that is realized in each of the first seven years following the achievement of compliance at a facility. After seven years, this fraction remains 1.0 for 23 additional years. After these combined 30 years the facility is assumed to cease compliance, which is consistent with the time period over which costs are evaluated.

In the same way that the benefits profile builds up over time following compliance, the benefits profile declines at the end of the compliance period. Specifically, in the seven years following the end of compliance, the fraction of the steady state benefit value achieved follows the profile of <1.0, 0.9, 0.8, 0.2, 0.1, 0.05, 0.0>. Therefore, the analysis of benefits encompasses a 37-year facility compliance period starting with the first year of compliance. There are 35 years when benefits do not equal zero for a facility; 25 years when benefits are 100%; 10 years when benefits are a percentage of the total. These profile values are approximations based on a review of the age-specific fishing mortality rates that were used in the I&E analysis and best professional judgment.

For regions with a relatively high contribution of impingement to total I&E (Inland, Great Lakes, and the Gulf of Mexico regions), EPA used an adjusted benefits profile of <0.1, 0.2, 0.8, 0.9, 0.95, 1.0>. This adjusted profile reflects that impinged fish are usually larger and older than entrained fish and thus benefits will be realized sooner in these regions. These profile values are approximations based on a review of the age-specific fishing mortality rates that were used in the I&E analysis and best professional judgment.

A8-2 Discounting and Annualization

Using the time profile of benefits discussed above, EPA discounted the total benefits generated in each year of the analysis to 2007 using the following formula:

$$\text{Present value} = \sum_t \frac{\text{Benefits}_t}{(1 + r)^{t-2007}} \qquad \text{(Equation 1)}$$

where:

Benefits_t = benefits in year t
r = discount rate (3% and 7%)
t = year in which benefits are incurred (2007 to 2043)

After calculating the present value (PV) of these benefits streams, EPA calculated their constant annual equivalent value (annualized value) using the annualization formula presented below, again using two discount rates, 3% and 7%.[2] Although the analysis period extends from 2007 through 2048, a compliance period of 42 years for all facilities, EPA annualized benefits over 30 years, since 30 years is the assumed period of compliance. This same annualization concept and period of annualization were also followed in the analysis of costs, although for costs the time horizon of analysis for calculating the present value is shorter than for benefits. Using a 30-year annualization period for both benefits and social costs allows comparison of constant annual equivalent values of benefits and costs that have been calculated on a mathematically consistent basis. The annualization formula is as follows:

$$\text{Annualized Benefit} = \text{PV of Benefit} * \left(\frac{r * (1+r)^{(n-1)}}{(1+r)^n - 1} \right) \qquad \text{(Equation 2)}$$

where:

r = discount rate (3% and 7%)
n = annualization period, 30 years for the benefits analysis

Table A8-1 presents an illustrative summary of the time profile of undiscounted benefits for one of the regulatory analysis options, for each region and for the entire U.S. The table also presents the total discounted value and annualized value that are equivalent to this stream of undiscounted benefits.

Table A8-1: Time Profile of Mean Total Use Benefits for the "50 MGD for All Waterbodies" Option (thousands 2004$)[a,b]

Year	California	North Atlantic	Mid-Atlantic	Gulf of Mexico	Great Lakes	Inland	National Total
2007	$0	$0	$0	$0	$0	$0	$0
2008	$0	$0	$0	$0	$0	$0	$0
2009	$0	$0	$0	$0	$0	$0	$0
2010	$0	$0	$0	$0	$3	$6	$9
2011	$3	$0	$2	$0	$30	$29	$64
2012	$7	$1	$3	$165	$75	$84	$335
2013	$27	$3	$22	$330	$249	$195	$825
2014	$30	$11	$36	$1,320	$315	$235	$1,946
2015	$32	$13	$96	$1,484	$460	$291	$2,377
2016	$33	$19	$125	$1,567	$495	$313	$2,552

---

[2] The 3% rate represents a reasonable estimate of the social rate of time preference. The 7% rate represents an alternative discount rate, recommended by the Office of Management and Budget (OMB), that reflects the estimated opportunity cost of capital.

Table A8-1: Time Profile of Mean Total Use Benefits for the "50 MGD for All Waterbodies" Option (thousands 2004$)[a,b]

Year	California	North Atlantic	Mid-Atlantic	Gulf of Mexico	Great Lakes	Inland	National Total
2017	$33	$20	$133	$1,649	$507	$318	$2,662
2018	$33	$21	$139	$1,649	$518	$322	$2,683
2019	$33	$21	$141	$1,649	$518	$323	$2,685
2020	$33	$21	$141	$1,649	$518	$323	$2,685
2021	$33	$21	$141	$1,649	$518	$323	$2,685
2022	$33	$21	$141	$1,649	$518	$323	$2,685
2023	$33	$21	$141	$1,649	$518	$323	$2,685
2024	$33	$21	$141	$1,649	$518	$323	$2,685
2025	$33	$21	$141	$1,649	$518	$323	$2,685
2026	$33	$21	$141	$1,649	$518	$323	$2,685
2027	$33	$21	$141	$1,649	$518	$323	$2,685
2028	$33	$21	$141	$1,649	$518	$323	$2,685
2029	$33	$21	$141	$1,649	$518	$323	$2,685
2030	$33	$21	$141	$1,649	$518	$323	$2,685
2031	$33	$21	$141	$1,649	$518	$323	$2,685
2032	$33	$21	$141	$1,649	$518	$323	$2,685
2033	$33	$21	$141	$1,649	$518	$323	$2,685
2034	$33	$21	$141	$1,649	$518	$323	$2,685
2035	$33	$21	$141	$1,649	$518	$323	$2,685
2036	$33	$21	$141	$1,649	$518	$323	$2,685
2037	$33	$21	$141	$1,649	$518	$323	$2,685
2038	$33	$21	$141	$1,649	$518	$323	$2,685
2039	$33	$21	$141	$1,649	$518	$323	$2,685
2040	$33	$21	$141	$1,649	$515	$316	$2,676
2041	$30	$21	$139	$1,649	$488	$294	$2,622
2042	$27	$20	$138	$1,484	$444	$238	$2,351
2043	$7	$18	$119	$1,320	$269	$127	$1,860
2044	$3	$10	$105	$330	$203	$87	$739
2045	$2	$8	$45	$165	$58	$31	$309
2046	$0	$2	$16	$82	$23	$10	$133
2047	$0	$1	$8	$0	$11	$4	$24
2048	$0	$0[e]	$2	$0	$0	$0[e]	$2
Undiscounted							
Total Present Value[c]	$1,004	$629	$4,228	$49,483	$15,543	$9,676	$80,563
Annualized Value[d]	$33	$21	$141	$1,649	$518	$323	$2,685
Evaluated at 3% Discount Rate							
Total Present Value[c]	$565	$336	$2,244	$27,050	$8,543	$5,389	$44,128
Annualized Value[d]	$29	$17	$115	$1,380	$436	$275	$2,251

Table A8-1: Time Profile of Mean Total Use Benefits for the "50 MGD for All Waterbodies" Option (thousands 2004$)[a,b]

Year	California	North Atlantic	Mid-Atlantic	Gulf of Mexico	Great Lakes	Inland	National Total
Evaluated at 7% Discount Rate							
Total Present Value[c]	$296	$165	$1,090	$13,631	$4,341	$2,786	$22,308
Annualized Value[d]	$24	$13	$88	$1,098	$350	$224	$1,798

[a] The estimate of the total use value of I&E reductions includes recreational and commercial fishing benefits. EPA estimated non-use benefits qualitatively.
[b] Note that all monetary values in this table are expressed in thousands 2004$, since EPA did not adjust the values for inflation.
[c] The total present value is equal to the sum of the values of the benefits realized in all years of the analysis, discounted to 2007.
[d] The annualized value represents the total present value of the benefits of the regulation, distributed over a thirty year period.
[e] Positive non-zero value less than $500.

Source: U.S. EPA analysis for this report.

Chapter A9: Threatened & Endangered Species Analysis Methods

Introduction

Threatened and endangered (T&E) and other special status species[1] can be adversely affected in several ways by cooling water intake structures (CWIS). T&E species can suffer direct harm from impingement and entrainment (I&E), they can suffer indirect impacts if I&E at CWIS adversely affects another species upon which the T&E species relies (e.g., as a food source), or they can suffer impacts if the CWIS disrupts their critical habitat. The loss of individuals of listed species from CWIS is particularly important because, by definition, these species are already rare and at risk of irreversible decline because of other stressors.

This chapter provides information relevant to an analysis of listed species in the context of the section 316(b) regulation; defines species considered as threatened, endangered, or of special concern; gives a brief overview of the potential for I&E-related adverse impacts on T&E species; and describes methods available for considering the economic value of such impacts.

EPA was unable to evaluate the presence of T&E species near potentially regulated Phase III facilities because it was able to obtain only 20 Phase III studies. The lack of information on T&E species at Phase III facilities may be a function of this limited number of impingement and entrainment studies.

However, a number of Phase II facilities have documented impingement and entrainment of T&E species. Chapters B-H provide information on the federally listed T&E species present in each region of EPA's Phase III analysis.

Chapter Contents

A9-1 Listed Species Background A9-1
  A9-1.1 Federally Listed Species Definitions A9-2
  A9-1.2 Main Factors in Listing of Aquatic Species.............................. A9-2
  A9-1.3 "Incidental Take" Permits A9-3
A9-2 Benefit Categories Applicable for Impacts on T&E Species....................................... …..A9-4
A9-3 Methods Available for Estimating the Economic Value Associated with I&E of T&E Species.. A9-5
  A9-3.1 Estimating I&E Impacts on T&E Species A9-5
  A9-3.2 Economic Valuation Methods......... A9-5
A9-4 Issues in Estimating and Valuing Environmental Impacts from I&E on T&E Species.. A9-12
  A9-4.1 Issues in Estimating the Size of the Population of Special Status Species A9-12
  A9-4.2 Issues Associated with Estimating I&E Contribution to the Cumulative Impact from All Stressors................................. A9-12
  A9-4.3 Issues Associated with Implementing an Economic Valuation Approach...................... A9-12

A9-1 Listed Species Background

The federal government and individual states develop and maintain lists of species that are considered endangered, threatened, or of special concern. The federal and state lists are not identical: a state does not list a

---

[1] To simplify the discussion, in this chapter EPA uses the terms "T&E species" and "special status species" interchangeably to mean all species that are specifically listed as threatened or endangered, plus any other species that has been given a special status designation at the state or federal level.

species that is on the federal list if it is extirpated in the state. States may also list a species that is not on the federal list if the species is considered threatened or endangered at the state, but not federal, level.

The federal trustees for T&E species are the Department of the Interior's U.S. Fish and Wildlife Service (U.S. FWS) and National Oceanic and Atmospheric Administration (NOAA) Fisheries. Both departments are also referred to herein as the Services. The U.S. FWS is responsible for migratory birds and terrestrial and freshwater species (including plants), whereas NOAA Fisheries deals with marine species and anadromous fish (USFWS, 1996b). At the state level, the departments, agencies, or commissions with jurisdiction over T&E species include Fish and Game; Natural Resources; Fish and Wildlife Conservation; Fish, Wildlife and Parks; Game and Parks; Environmental Conservation; Conservation and Natural Resources; Parks and Wildlife; the states' Natural Heritage Programs, and several others.

In the remainder of this chapter, and in the regional sections of this document, EPA focuses on federally listed T&E species based on information in the U.S. FWS' Threatened and Endangered Species System (TESS) database (USFWS, 2006a), available at http://www.fws.gov/endangered/wildlife.html.

Information on both federal and state listed species is available online in the NatureServe database (NatureServe, 2006) at http://www.natureserve.org/explorer/. For additional information on state listed species, it is best to contact the T&E coordinator in the particular state of interest.

A9-1.1 Federally Listed Species Definitions

a. Threatened and endangered species

A species is federally listed as "endangered" when it is *likely to become extinct* within the foreseeable future throughout all or part of its range if no immediate action is taken to protect it. A species is listed as "threatened" if it is *likely to become endangered* within the foreseeable future throughout all or most of its range if no action is taken to protect it. Species are selected for listing based on petitions, surveys by the Services or other agencies, and other substantiated reports or field studies. The 1973 Endangered Species Act (ESA) outlines detailed procedures used by the Services to list a species, including listing criteria, public comment periods, hearings, notifications, time limits for final action, and other related issues (USFWS, 1996b).

A species is considered to be federally threatened or endangered if one or more of the following listing criteria apply (USFWS, 1996b):

- the species' habitat or range is currently undergoing or is jeopardized by destruction, modification, or curtailment;
- the species is overused for commercial, recreational, scientific, or educational purposes;
- the species' existence is vulnerable because of predation or disease;
- current regulatory mechanisms do not provide adequate protection; or
- the continued existence of a species is affected by other natural or man-made factors.

b. Species of concern

States and the federal government have also included species of "special concern" on their lists. These species have been selected because they are (1) rare or endemic, (2) in the process of being listed, (3) considered for listing in the future, (4) found in isolated and fragmented habitats, or (5) considered a unique or irreplaceable state resource.

A9-1.2 Main Factors in Listing of Aquatic Species

Numerous physical and biological stressors have resulted in the listing of aquatic species. The major factors include habitat destruction or modification, displacement of populations by exotic species, dam building and impoundments, increased siltation and turbidity in the water column, sedimentation, various point and non-point sources of pollution, poaching, and accidental catching. Some stresses, such as increased contaminant loads or turbidity, can be alleviated by water quality programs such as the National Pollutant Discharge Elimination System (NPDES) or the current EPA efforts to develop Total Maximum Daily Loads (TMDLs). Other factors, such as dam building or habitat modifications for flood control purposes, are relatively permanent and therefore more difficult to mitigate. In addition to these major factors, negative effects of CWIS on some listed species have been documented.

A9-1.3 "Incidental Take" Permits

Congress amended the ESA in 1982 and established a legal mechanism authorizing the Services to issue permits to non-federal entities — including individuals, private businesses, corporations, local governments, state governments, and Tribal governments — who engage in the "incidental take" of federally-protected wildlife species (plants are not explicitly covered by this program). Incidental take is defined as take that is "incidental to, and not the purpose of, the carrying out of an otherwise lawful activity under local, State or Federal law." Examples of lawful activities that may result in the incidental take of T&E species include developing private or state-owned land containing habitats used by federally-protected species, or the withdrawal of cooling water that may impinge or entrain federally-protected aquatic species present in surface waters.

An integral part of the incidental take permit process is development of a Habitat Conservation Plan (HCP). An HCP provides a counterbalance to an incidental take by proposing measures to minimize or mitigate the impact and ensuring the long-term commitment of the non-federal entity to species conservation. HCPs often include conservation measures that benefit not only the target T&E species, but also proposed and candidate species, and other rare and sensitive species that are present within the plan area (USFWS and NMFS, 2000). The ESA stipulates the major points that must be addressed in an HCP, including the following (USFWS and NMFS, 2000):

- defining the potential impacts associated with the proposed taking of a federally-listed species;
- describing the measures that the applicant will take to monitor, minimize, and mitigate these impacts, including funding sources[2];
- analyzing alternative actions that could be taken by the applicant and reasons why those actions cannot be adopted; and
- describing additional measures that the Services may require as necessary or appropriate.

HCP permits can be issued by the Services' regional directors if:

- the taking will be incidental to an otherwise lawful activity;
- any impacts will be minimized or fully mitigated;
- the permittee provides adequate funding to fully implement the permit;
- the incidental taking will not reduce the chances of survival or recovery of the T&E species; and
- any other required measures are met.

The Services have published a detailed description of the incidental take permit process and the habitat conservation planning process (USFWS and NMFS, 2000). The federal incidental take permit program has only limited application within the context of the section 316(b) regulation because many T&E species (fish in particular) are listed mainly by states, not by the Services, and hence fall outside of the jurisdiction of this program.

---

[2] Mitigation can include preserving critical habitats, restoring degraded former habitat, creating new habitats, modifying land use practices to protect habitats, and establishing buffer areas around existing habitats.

A9-2 Benefit Categories Applicable for Impacts on T&E Species

Estimating the economic benefits of helping to preserve T&E and other special status species, such as by reducing I&E impacts, is difficult due to a lack of knowledge of the ecological role of different T&E species and a relative paucity of economic studies focusing on the benefits of T&E preservation. Most of the wildlife economic literature focuses on recreational use benefits that may be irrelevant for valuation of T&E species because T&E species (e.g., the delta smelt in California) are not often targeted by recreational or commercial fishers. The numbers of special status species that are recreationally or commercially fished (e.g., shortnose sturgeon in the Delaware Estuary) have been so depleted that any use estimates associated with angling participation or landings data for recent years (or decades) would not be indicative of the species' potential value for direct use if and when the population recovers. Nevertheless, there are some T&E species for which consumptive use-related benefits could be significant once the numbers of individuals are restored to levels that enable resumption of relevant uses.

Based on their potential uses, T&E species can be divided into three broad categories:

- *T&E species with high potential for consumptive uses.* The components of total value of such species are likely to include consumptive, non-consumptive, and indirect use values, as well as existence and option values. Pacific salmon, a highly prized game species, is a good example of such species. In addition to having a high consumptive use value, this species is likely to have a high non-consumptive use value as well, because people who never go fishing may still watch salmon runs. The use value may actually dominate the total economic value of enhancing a T&E fish population for species like salmon. For example, Olsen et al. (1991) found that users contribute 65% to the total regional willingness-to-pay (WTP) value ($171 million in 1989$) for doubling the Columbia River salmon and steelhead runs. Non-users with zero probability of participation in the sport fishery contributed 25%. Non-users with some probability of future participation contributed the remaining 10%.

- *T&E species that do not have consumptive uses, but are likely to have relatively large non-consumptive and indirect use values.* The total value of such species would include non-consumptive use and indirect values and existence values. Loggerhead sea turtles can represent such species. The non-consumptive use of loggerhead sea turtles may include photography or observation of nesting or swimming reptiles. For example, a study by Whitehead and Bloomquist (1992) reports that the average subjective probability that North Carolina residents will visit the North Carolina coast for non-consumptive use recreation is 0.498. Policies that protect loggerhead sea turtles may therefore enhance individual welfare for a large group of participants in turtle viewing and photography.

- *T&E species whose total value is a pure non-use value*. Some prominent T&E species with minimal or no use values may have high non-use values. The bald eagle and the gray whale are examples of such species. Conversely, many T&E species with little or no use value are not well known or of significant public interest and therefore their non-use values may be challenging for individuals to report. Most obscure T&E species, which may have ecological, biological diversity, and other non-use values, are likely to fall into this category.

Non-use motives are often the principal source of benefits estimates for T&E species because many T&E species fall into the "obscure species" group. As described in greater detail in Chapter A3, motives often associated with non-use values held for T&E species include bequest (i.e., intergenerational equity) and existence (i.e., preservation and stewardship) values. These non-use values are not necessarily limited to T&E species, but I&E-related adverse impacts to these unique species would be locally or globally irreversible, leading to extinction being a relevant concern. Irreversible adverse impacts on unique resources are not a necessary condition for the presence of significant non-use values, but these attributes (e.g., uniqueness; irreversibility; and regional, national, or international significance) would generally be expected to generate relatively high non-use values (Harpman et al., 1993; Carson et al., 1999).

A9-3 Methods Available for Estimating the Economic Value Associated with I&E of T&E Species

Estimating the value of increased protection of T&E species from reducing I&E impacts requires the following steps:

- estimating I&E impacts on T&E species; and
- attaching an economic value to changes in T&E status from reducing I&E impacts on species of concern (e.g., increasing species population, preventing species extinction).

A9-3.1 Estimating I&E Impacts on T&E Species

Several cases of I&E of federally-protected species by CWIS are documented, including the delta smelt in the Sacramento-San Joaquin River Delta, sea turtles in the Delaware Estuary and elsewhere (NMFS, 2001b), shortnose sturgeon eggs and larvae in the Hudson River (NYSDEC, 2003), and pallid sturgeon eggs and larvae in the Great Rivers Basin (Dames & Moore, 1977). Mortality rates vary by species and life stage: it is estimated to range from 2 to 7% for impinged sea turtles (NMFS, 2001b), but mortality can be expected to be much higher for entrained eggs and larvae of the shortnose sturgeon and other special status fish species. The estimated yearly take of delta smelt by CWIS in the Sacramento-San Joaquin River Delta led to the development of a Habitat Conservation Plan as part of an incidental take permit application (Southern Energy Delta LLC, 2000).

A9-3.2 Economic Valuation Methods

Valuing impacts on special status species requires using nonmarket valuation methods to assign likely values to losses of these individuals. The fact that many of these species typically are not commercially or recreationally harvested (once they are listed) means no market value can be placed on their consumption. Benefits estimates are therefore often confined to non-use values for special status species. The total economic value of preserving species with potentially high use values (i.e., T&E salmon runs) should include both use and non-use values. Economic tools allowing estimates of both use and non-use values (e.g., stated preference methods) may be suitable for calculating the benefits of preserving T&E species. The relevant methods are briefly summarized below.

It is necessary to note that the benefits of preserving T&E species estimated to date reflect a human-centered view; benefit cost analysis may need to be supplemented with other analyses when T&E species are involved because extinction is irreversible.

a. Stated preference methods

As described in Chapter A3, the only available way to directly estimate non-use values for special status species is through applying stated preference methods, such as the contingent valuation method (CVM). This method relies on statements of intended or hypothetical behavior elicited though surveys to value species. CVM has sometimes been criticized, especially in applications dating back a decade or more, because the analyst cannot verify whether the stated values are realistic and absent of various potential biases. CVM and other stated preference techniques (including conjoint analysis) have evolved and improved in recent years, however, and empirical evidence shows that the method can yield reliable (and perhaps even conservative) results where stated preference results are compared to those from revealed preference estimates (e.g., angling participation as observable behavior) (Carson et al., 1996).

b. Benefit transfer approach

Using a benefit transfer approach may be a viable option in some cases. By definition, benefit transfer involves extrapolating the benefits findings estimated from one analytic situation to another situation(s). The initial analytic situation is defined in terms of an environmental resource (e.g., T&E species), the policy variable(s) (e.g., changes in species status or population), and the benefiting populations being investigated. Only in ideal circumstances do the environmental resource and policy variables of the original study very closely match those of the analytic situation to which a policy or regulatory analyst may wish to extrapolate study results. Despite discrepancies, this approach may provide useful insights into benefits to society from reducing stress on T&E species.

The current approach to benefit transfers most often focuses on the meta-analysis of point estimates of the Hicksian or Marshalian surplus reported from original studies. If, for example, the number of candidate studies is small and the variation of characteristics among the studies is substantial, then meta-analysis is not feasible. This is likely to be the case when T&E species are involved, requiring a more careful consideration of analytic situations in the original and policy studies. If only one or a few studies are available, an analyst evaluates their transferability based on technical criteria developed by Desvousges et al. (1992).

EPA illustrated the *economic* value to society of protecting T&E species by conducting a review of the contingent valuation (CV) literature that estimates WTP to protect those species. This review focused on those studies valuing those aquatic species that may be at risk of I&E by CWIS. EPA also identified studies that provide WTP estimates for fish-eating species, i.e., the bald eagle, peregrine falcon, and the whooping crane. These species may also be at risk because they rely to some degree on aquatic organisms as a food source. EPA used select studies identified in a meta-analysis that Loomis and White (1996) conducted as a literature base. Loomis and White included all rare or endangered species in their analysis, but EPA limited its own literature review to those studies that valued threatened or endangered aquatic species, or birds that consume aquatic species. Table A9-1 lists the 14 relevant CV studies that EPA identified and provides corresponding WTP estimates and selected study characteristics. WTP estimates represent either one-time payments, annual payments, or an annual payment in a 5-year program. The table indicates which of these payment types each WTP estimate represents, along with the corresponding value, inflated to 2004$. EPA also converted lump-sum payments and 5-year program annual payments into annualized values in order to aid in the comparison of values from all studies.[3]

The identified valuation studies vary in terms of the species valued and the specific environmental change valued. Thirteen of these studies represent a total of 16 different species. In addition, one study (Walsh et al., 1985) estimates WTP for a group of 26 species. Most of these studies value prominent species well known by the public, such as salmon. The studies valued one of the following general types of environmental changes:

- avoidance of species loss/extinction;
- species recovery/gain;
- acceleration of the recovery process;
- improvement of an area of a species' habitat; and
- increases in species population.

In order to compare consistent measures of WTP, EPA chose to use values that represent either annual or annualized WTP, which represent conservative estimates of consumer surplus. These measures are conservative because the value of preserving or improving populations of T&E species reported in T&E valuation studies has a wide range. Mean annual (or annualized) household WTP estimates of obscure aquatic species range from $7.89 (2004$) for the striped shiner (Boyle and Bishop, 1987) to $8.73 for the silvery minnow (Berrens et al., 1996). It is not likely that use values associated with these species are significant.

---

[3] For each study that presents annual payments in a 5-year program, EPA calculated the present value of those payments using a 3% discount rate, and annualized present day value over 25 years using the same discount factor. EPA considered lump-sum payments to represent present value, and thus merely annualized these payments using the same assumptions.

WTP for prominent fish species range from the relatively low estimate of $2.40 (2004$; Stevens et al., 1991), to $9.16 (Stevens et al., 1991); both values are mean non-user WTP for Atlantic salmon, and are annualized. Total user values are much higher for Atlantic salmon, as this species is commonly targeted by recreational anglers.[4] WTP estimates for fish-eating species (i.e., whooping crane, bald eagle, and peregrine falcon), which all have high non-use values (i.e., existence value), range from $4.60 (Carson et al., 1994) to $65.15 (Bowker and Stoll, 1988). It is important to note that the above WTP ranges are derived from studies that used various valuation scenarios and valued different types of environmental changes, and therefore should be viewed as approximate values as opposed to finite ranges.

It may be possible to develop individual WTP ranges for a given species or species group based on the estimated changes in T&E status (e.g., species gain or recovery) from reducing I&E impacts and the applicable WTP values from existing studies.

Once individual WTP for protecting T&E species or increasing their population is developed, the next step is to estimate total benefits from reducing I&E of the special status species. The analyst should apply the estimated WTP value to the relevant population groups to estimate the total value of improving protection of T&E species. The affected population may include both potential users and non-users, depending on species type. The relevant population may also include area residents, regional population, or, in exceptional cases (e.g., bald eagle), the U.S. population. The total value of improved protection of T&E species (e.g., preventing extinction or doubling the population size) should be then adjusted to reflect the percentage of cumulative environmental stress attributable to I&E.

c. Cost of T&E species restoration

Under specific circumstances it is possible to infer how much value society places on a program or activity by observing how much society is willing to forego (in out-of-pocket expenses and opportunity costs) to implement the program. For example, the costs borne by society to implement programs that preserve and restore special status species can, under select conditions, be interpreted as a measure of how much society values the outcomes it anticipates receiving. This approach is analogous to the broadly accepted revealed preference method of inferring values for private goods and services based on observed individual behavior.

In the case of observed individual behavior, when a person willingly bears a cost (pays a price) to receive a good or service, then it is deduced that the person’s value for that acquired good or service must be at least as great as the price paid. That is, based on the presumption that individual behavior reflects the economic rationality of seeking to maximize utility (well-being), the person’s observed WTP must exceed the price paid, otherwise they would not have purchased that unit of the commodity. The approach described in this section uses the same premise, but applies it to societal choices rather than to a single individual’s choices.

A critical issue with the approach is determining when it is likely that a specific public sector activity (or other form of collective action) does indeed reflect a “societal choice.” Not every policy enacted by a public sector entity can be interpreted as an indication of social choice. Hence, the costs imposed in such instances may not in any way reveal social values. For example, some regulatory actions may have monetized social costs that outweigh the monetized social benefits, but an action may be tougher because of legal requirements or other considerations. In such a case, asserting that the costs imposed reflect a lower bound estimate of the “value” of the action would not be accurate (the values may be less than the imposed costs). Alternatively, there are some regulatory programs for which the benefits greatly exceed costs, and in such instances using costs as a reflection of value would greatly understate social benefits.

---

[4] See Chapter A5 of this report for details on recreational fishing values for Atlantic salmon.

Table A9-1: WTP for Improving T&E Species Populations[a]

Species Type	Reference	Publication Date	Survey Date	Species	Environmental Change	Size of Change	Value Type[b]	Mean WTP (2004$)	Annual or Annualized Mean WTP (2004$)[c]	CVM Method	Survey Region	Sample Size	Response Rate	Payment Vehicle
Aquatic	Berrens et al.	1996	1995	Silvery minnow	Maintain instream flow to protect species		5	$34.69	$8.73	DC	NM households	698	45%	Trust fund
	Boyle and Bishop	1987	1984	Striped shiner	Avoid loss	100%	A	$7.89	$7.89	DC	WI households	365	73%	Foundation
	Carson et al.	1994	1994	Kelp bass, white croaker, bald eagle, peregrine falcon	Speed recovery from 50 to 5 years		L	$82.64	$4.61	DC	CA households	2,810	73%	One-time tax
	Cummings et al.	1994	1994	Squawfish	Avoid loss	100%	A	$11.00	$11.00	OE	NM	921	42%	Increase state taxes
	Duffield and Patterson	1992	1992	Arctic grayling	Improve 1 of 3 rivers		L	$22.69	$1.27	PC	U.S. visitors	157	27%	Trust fund
				Cutthroat trout			L	$17.02	$0.94	PC	U.S. visitors	170	77%	Trust fund
	Kotchen and Reiling	2000	1997	Shortnose sturgeon	Recovery to self-sustaining population		L	$31.33	$1.74	DC	Maine residents (random)	635	63%	One-time tax
	Loomis and Larson	1994	1991	Gray whale	Gain	50%	A	$22.41	$22.41	OE	CA households	890	54%	Protection fund
					Gain	100%	A	$25.13	$25.13	OE	CA households	890	54%	Protection fund
					Gain	50%	A	$34.63	$34.63	OE	CA visitors	1,003	72%	Protection fund

Table A9-1: WTP for Improving T&E Species Populations[a]

Species Type	Reference	Publication Date	Survey Date	Species	Environmental Change	Size of Change	Value Type[b]	Mean WTP (2004$)	Annual or Annualized Mean WTP (2004$)[c]	CVM Method	Survey Region	Sample Size	Response Rate	Payment Vehicle
	Loomis and Larson (cont.)	1994	1991	Gray whale	Gain	100%	A	$41.18	$41.18	OE	CA visitors	1,003	72%	Protection fund
	Olsen et al.	1991	1989	Pacific salmon and steelhead	Gain (existence value)	100%	A	$40.90	$40.90	OE	Pac. NW household	695	72%	Electric bill
					Gain (user value)	100%	A	$115.53	$115.53	OE	Pac. NW anglers	482	72%	Electric bill
	Stevens et al.	1991	1989	Atlantic salmon	Avoid loss	100%	5	$9.53	$2.40	DC	MA households	169	30%	Trust fund
				Atlantic salmon	Avoid loss	100%	5	$10.58	$2.67	OE	MA households	169	30%	Trust fund
		1994	1993	Atlantic salmon	Gain	50%	5	$25.39	$6.39	DCOE	College students	76	93%	Contribution
				Atlantic salmon	Gain	90%	5	$36.46	$9.17	DCOE	College students	76	93%	Contribution
	Walsh et al.	1985	1985	26 species in CO	Avoid loss	100%	A	$75.80	$75.80	OE	CO households	198	99%	Taxes
	Whitehead and Bloomquist	1992	1991	Sea turtle	Avoid loss	100%	L	$16.97	$0.94	DC	NC households	207	35%	Preservation fund
Fish-eating birds	Bowker and Stoll	1988	1983	Whooping crane	Avoid loss	100%	A	$41.58	$41.58	DC	TX and U.S. visitors	316	36%	Foundation
				Whooping crane	Avoid loss	100%	A	$65.24	$65.24	DC	TX and U.S. visitors	254	67%	Foundation
	Boyle and Bishop	1987	1984	Bald eagle	Avoid loss	100%	A	$20.12	$20.12	DC	WI households	365	73%	Foundation
	Carson et al.	1994	1994	Bald eagle, peregrine falcon, kelp bass, white croaker	Speed recovery from 50 to 5 years		L	$82.64	$4.61	DC	CA households	2,810	73%	

Table A9-1: WTP for Improving T&E Species Populations[a]

Species Type	Reference	Publi-cation Date	Survey Date	Species	Environ-mental Change	Size of Change	Value Type[b]	Mean WTP (2004$)	Annual or Annualized Mean WTP (2004$)[c]	CVM Method	Survey Region	Sample Size	Response Rate	Payment Vehicle
	Stevens et al.	1991	1989	Bald eagle	Avoid loss	100%	A	$43.05	$43.05	DCOE	NE households	339	37%	Trust fund
				Bald eagle	Avoid loss	100%	A	$30.33	$30.33	DCOE	NE households	339	37%	Trust fund
	Swanson	1993	1991	Bald eagle	Increase in populations	300%	L	$332.76	$18.55	DC	WA visitors	747	57%	Membership fund
				Bald eagle	Increase in populations	300%	L	$233.08	$13.00	OE	WA visitors	747	57%	Membership fund

[a] Exhibit adapted from Loomis and White (1996) and includes only those studies that valued aquatic species or fish-eating birds.

[b] Indicates type/length of WTP payment reported in study: 5 = annual payment in 5-year program; L = lump-sum, or one-time, payment; A = annual payment.

[c] Lump-sum values are annualized over 25 years using a 3% discount rate; values that are annual payments in 5-year programs were converted into present value before annualizing over 25 years at a 3% discount rate; annual payments are presented as in the original study, inflated to 2004$ using the Consumer Price Index (CPI). Values that already represent annual values are unadjusted.

Sources: Loomis and White, 1996; CPI: U.S. Bureau of Labor Statistics, 2004.

There are some public policy actions that can be suitably interpreted as expressions of societal preferences and values. In these instances, the incurred costs may be viewed as an indication of social values. The criteria to help identify when such situations arise include whether the actions taken are voluntary, or whether the actions reflect an open and broadly inclusive policy-making process that enables and encourages active participation by a broad spectrum of stakeholders. This is especially relevant where (1) plans and actions are developed in an inclusive, consensus-building manner; (2) implementation steps are pursued in an adaptive management framework that enables continuous feedback and refinement; or (3) the actions are ultimately supported by some positive indication of broad community support, such as voter approval of a referendum. In such instances, the policy choices made are the product of a broad-based, collective decision-making process, and such programs can be viewed as an expression of societal preferences. When programs or activities stem from such open collective processes, the actions (and costs incurred) may reflect the revealed preference of society.

EPA’s method of valuing T&E species results in a three-step process. First, using the criteria above, EPA determines which action can be viewed as reflecting societal preferences. Next, estimates of costs incurred and anticipated from voluntary or other suitable collective actions taken to maintain and or increase the populations of T&E species (e.g., restoration of critical spawning or nursery habitat) are combined with estimates of the value of any foregone opportunities (i.e., opportunity costs, where direct costs are not involved) from additional actions required to achieve the T&E population objectives (e.g., maintaining instream flows for a species instead of providing water for agricultural diversions). This resulting total social cost provides a cumulative estimate of society’s valuation of the preservation and enhancement of the T&E species affected by the actions. Categories of actions that would be addressed in this step could include private and public expenditures on habitat restoration/population enhancement programs, funds that have been allocated for such actions through legislative appropriations or public referenda (even if not yet expended), or resources allocated through a formal project evaluation and selection process designed to allocate limited resources such as those used by numerous state and federal resource management agencies.

Third, the numbers of the T&E organisms that are expected to benefit from the identified actions, as measured by the increased production or avoided losses of individuals, are estimated to place the valuation estimates in context. If dollar per organism results are required for a valuation analysis, as is the case in this analysis, the estimates from the second step can be divided by the increased production (avoided loss) estimate from the third step to provide such results.

The economic foundations for using this approach to value T&E species are established through the widespread recognition and acceptance of revealed preference data as a source of nonmarket information that is acceptable for the valuation of resources. As discussed above, in EPA’s approach, valuation estimates rely on the costs of actions or the value of foregone opportunities that are *voluntarily* undertaken or that have been approved through extensive public input and review (and developed in a consensus-oriented approach). With these sources of data, the method avoids the well-established problems associated with using “costs” as a measure of “value” — a problem that can arise when the cost is realized involuntarily (e.g., avoided cost-based measures of value). Specifically, because of the available evidence of the public’s acceptance and willingness to incur the opportunity costs associated with the actions that are selected for evaluation, the fundamental criteria for defining the value of any resource are satisfied.

One issue that arises with the use of the method is that it is not clear that the resulting values can be distinctly categorized as direct use or non-use values because the underlying actions benefiting the T&E species could reflect an expressed mix of non-use values (e.g., preservation and existence) and discounted future use values (i.e., the actions are seen as an “investment” that could return the species to levels at which direct use would be permitted). It is believed that results could provide an approximation of the total use value for the T&E species in question.

A9-4 Issues in Estimating and Valuing Environmental Impacts from I&E on T&E Species

Several technical and conceptual issues are associated with valuing I&E impacts on T&E species:

- issues associated with estimating the size of a species' population;
- issues associated with estimating the contribution of I&E to the cumulative impacts of all stressors; and
- issues associated with implementing an economic valuation approach.

A9-4.1 Issues in Estimating the Size of the Population of Special Status Species

Difficulties in estimating the number of individuals or size of the population of special status fish present *in a given location* are often very difficult for numerous reasons, including the following:

- the act of monitoring a T&E species is problematic in and of itself because, by definition, the species is rare, and monitoring can result in some harm to the species. Researchers and federal agencies can therefore be reluctant to undertake such monitoring;
- monitoring programs typically focus only on harvested species and so do not provide any information with regard to non-harvested T&E species that are subject to I&E; and
- the number of individuals of a T&E species may be so low that they rarely or never show up in monitoring programs.

Deriving population estimates from existing monitoring programs often means extrapolating monitoring sample catches to the population as a whole. The variance in estimates is likely to be very high because of several assumptions that must be met when extrapolating monitoring sample catches to population estimates in order to create an accurate estimate:

- species are completely recruited and vulnerable to the gear (i.e., are large enough to be retained by the mesh and do not preferentially occupy habitats not sampled) or selectivity of the gear by size is known;
- sampling fixed locations for species approximates random sampling;
- species are uniformly distributed through the water column;
- volume filtered by sampling trawls can be accurately estimated; and
- volumes of water can be estimated for each embayment in the habitat range for the species.

A9-4.2 Issues Associated with Estimating I&E Contribution to the Cumulative Impact from All Stressors

There are also issues associated with estimating the relative contribution of I&E to the total impact of all stressors on T&E species:

- Because, as outlined above, the size of populations of T&E species is hard to measure even if I&E data are available from facilities with cooling water intake structures, it may be difficult to determine how much of an impact I&E has on population levels. For very rare species, even relatively low levels of I&E may be important.
- There are often a number of stressors that harm or limit populations of special status fish. Even if significant numbers of fish are lost to I&E, other factors may still have a greater role in determining populations levels. For example, if lack of spawning areas is limiting population growth of a species, then reducing I&E of that species may not increase the population.

A9-4.3 Issues Associated with Implementing an Economic Valuation Approach

a. Issues associated with benefit transfer approach

The following issues may arise when using a benefit transfer approach:

- Some studies estimated WTP for multiple species. Values established by Walsh et al. (1985), Olsen et al. (1991), and Carson et al. (1994) are for groups of T&E species, and therefore transferring values from these studies to particular species may not be feasible.

- The type of environmental change valued in the study may not match the environmental changes resulting from reducing I&E impacts. As noted above, previous T&E valuation studies addressed one of the following qualitative changes in T&E status:
  - avoidance of species loss/extinction;
  - species recovery/gain;
  - acceleration of the recovery process;
  - improvement of an area of a species' habitat; and
  - increases in species population.

- The *size of the environmental change* that the hypothetical scenario defines is also vital for developing WTP estimates. Several studies describe programs that avoid the loss of a species. This outcome may be considered a 100% improvement with respect to the alternative, extinction, but the restoration of a species or the *increase* in population may be specified at any level (e.g., 50%, 300%). Swanson (1993) estimated a 300% increase in bald eagle populations and Boyle and Bishop (1987) estimated WTP to avoid the possibility of bald eagle *extinction* in Wisconsin (cited in Loomis and White, 1996). Although avoiding extinction may be considered a 100% improvement, this environmental change is not comparable to the 300% increase in existing populations. Preventing regional extinction is quite different than realizing a nominal increase in species population (in which the alternative is not necessarily species loss). Since different studies measure different types of improvements, creating a common metric with which to transfer values can be difficult.

- Although a considerable amount of CV literature has valued T&E species, such research is largely limited to species with high consumptive use or non-use values. They either have high recreational or commercial value, or are popularly valued as significant species for various reasons (e.g., national symbol, aesthetics). Transferring these values to other species may not be appropriate. Many T&E species that are likely to be affected by I&E (either federal or state-listed) are obscure, and WTP for their preservation has not been estimated.

b. Issues associated with cost of restoration approach

The following issues may arise when using a cost of restoration approach:

- "Restoration" programs need not be relied on exclusively to infer societal WTP to preserve special status species. In many instances, other programs or restrictions are used in lieu of (or in conjunction with) restoration programs. In these cases, the costs associated with the restoration components also reveal a WTP. Collecting all of these components may be challenging.

- Costs directed at a special status species must be isolated from program elements intended to address other species or problems. In a multifaceted restoration or use restriction program, the percentage of costs used mainly to target restoration of special status species as opposed to other ecosystem benefits needs to be estimated. Separating these components out for an accurate valuation can be challenging.

- Estimates of the change in species abundance associated with the program must be developed, since the size of the change in species abundance is necessary to determine societal WTP per individual. Often targets are set to abundance levels that existed before a significant decline in populations. However, a habitat restoration program may target restoration of special status species, but might not target a specific population size making calculation of societal WTP per individual difficult.